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# PARK DEVELOPMENT WITH WET DIGESTED SLUDGE

Seattle Metropolitan Municipality

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# PARK DEVELOPMENT WITH WET DIGESTED SLUDGE

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Project 17070 ENP

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16. Abstract

A four year study progressing from laboratory research to full scale demonstration project was conducted by the Municipality of Metropolitan Seattle (METRO) and the University of Washington Department of Civil Engineering to demonstrate the use of digested sewage sludge to reclaim seashore land.

A 100 gpm centrifuge was used to dewater digested sewage sludge with a normal feed consistency of 3 to 3.5 percent solids by dry weight. Approximately 10-15 tons/day of centrifuge cake was produced and placed in a diked area to reclaim land for park development. ~~It was concluded that~~ if the cake contains less than 50 percent water, a stable fill can be achieved. Design equations were developed to predict the settlement and drying of such sludge fills. No conclusive data could be developed within the allotted time that would insure that the public could safely use such a fill from the health standpoint. ~~It is concluded that~~ land reclamation costs, in the intertidal zone using digested centrifuge sludge will exceed $50 per ton of dry sludge if environmental impacts are properly controlled. (EPA abstract)

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## ABSTRACT

A 400 gpm centrifuge was used to dewater digested sewage sludge with a normal feed consistency of 3 to 3.5 percent solids by dry weight. Approximately 10-15 tons per day of centrifuge cake was produced and placed in a diked area to reclaim land for park development. Design and construction delays permitted less than one year to place and observe the behavior of the fill. Laboratory, bench scale, and pilot field studies were designed to complement the short field scale demonstration.

Based on these studies, it was concluded that if the cake contains less than 50 percent water, a stable fill can be achieved. Design equations were developed to predict the settlement and drying of such sludge fills. If wetter sludge is placed, serious rewetting and leaching problems can occur. No conclusive data could be developed within the allotted time that would insure that the public could safely use such a fill from the health standpoint. Longer observation of the fill is required to resolve this question.

The major disadvantages of land reclamation using the process demonstrated were identified as the possible health problem, the high cost of centrifuge maintenance, and the poor recovery of solids. Poor solids recovery adds costs of centrate treatment. Wetter sludges were produced to reduce maintenance costs and improve solids recovery. It is concluded that land reclamation costs, in the intertidal zone using digested centrifuge sludge will exceed $50 per ton of dry sludge if environmental impacts are properly controlled.

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# SECTION I

# CONCLUSIONS

## DEWATERING

1. The design and operation of a centrifuge for dewatering with digested sludge lacks a general body of knowledge to insure success. Major maintenance problems are encountered with wear and imbalance of the centrifuge. Solids recovery decreases with increasing cake dryness and chemicals must be added to increase solids recovery above fifty to sixty percent.

2. The use of an open throat progressing cavity type positive displacement pump for sludge cake handling is not practical for West Point sludge containing 50% solids.

3. A diesel-driven centrifuge should not be used if electrical drive is available.

4. Centrate treatment either by addition of chemicals to increase solids recovery in the cake or by direct treatment of centrate will double dewatering costs. The effectiveness of the chemicals is not readily predictable.

5. A centrifuge is not recommended as a sole means to dewater sludge for deep fills because of high maintenance costs and poor solids recovery.

## FILL

1. A stable fill can be developed from 50 percent water content sludge cake using standard earth-moving equipment.

2. The coliform content of the fill is high and does not diminish to acceptable levels in one year. (assuming human contact is possible)

3. Leachate and other environmental impacts of the fill can be minimized by dewatering the sludge to at least 50 percent solids.

4. Wetter sludges will increase in water content from rains and have a tendency to flow.

5. Vegetation can be used to significantly increase moisture removal from fills and reduce the drying period of wet sludges.

GENERAL

1. Temporary placement of sludge in intertidal zones is recommended at this time, but offsite disposal may offer more attractive alternatives.

2. A storage facility that can handle 5,000 cubic yards of sludge may be required to avoid serious environmental impacts during the wet season with any disposal system.

3. Both direct land disposal by spraying and thin layer application of dewatered sludges should be considered alternative methods to landfill.

## SECTION II

## RECOMMENDATIONS

The development of processes that can insure that public health and safety will be protected when disposing of sewage sludge is still needed. The cost of such development was found to be much greater than anticipated in this research. Not only are the analyses of pathogens, spores, viruses, etc. expensive, the pilot scale study of devices to control these agents in sludge was too costly for this effort. A major effort is required to resolve this potential problem if sludge disposal on land is to be practiced.

The observation of a deep fill for 12 months is too short a period to develop conclusive data on settlement and health impacts. It is recommended that the fill be monitored for five years before this process is evaluated.

Dewatering of sludge for deep fills requires improved design and operation of dewatering equipment. Better solids recovery will be required for any full scale operation. A belt rather than a pump system should be provided for sludge cake transport.

## SECTION III

## INTRODUCTION

Sludge disposal in an economic and environmentally acceptable fashion is a universal problem in wastewater treatment. Solutions have ranged from direct discharge into receiving waters to reclamation and reprocessing for its soil conditioning or energy value. A number of seacoast cities, including New York, San Francisco, Los Angeles, and Seattle, have or are still directly discharging sludge in coastal waters. Although this method is economical, the uncertainty of environmental impacts and the precedent it creates for regions that may lack the necessary dilution capacity has subjected this method to controversy. Both Federal and State agencies have instructed Metro to terminate the discharge of sludge into Puget Sound by 1973. In response to this directive, the Municipality of Metropolitan Seattle (METRO) enlisted the resources of the University of Washington, Department of Civil Engineering, to participate in a joint sludge disposal demonstration project.

The initial concept of the demonstration project was to develop a process that would employ wet digested sewage sludge to reclaim seashore land. This appeared to be attractive since the treatment plant is located on the shores of Puget Sound and the City of Seattle had expressed an interest in developing a parkway along the intertidal zone near the plant. Since there are many coast cities faced with sludge disposal problems and there was a great interest by public agencies in acquiring and developing lands for parkways, open spaces, and recreational areas, the concept of land reclamation with digested sludge appeared to be a solution to a nationwide problem.

The initial construction of the METRO West Point treatment facility provided a four-acre diked area in the intertidal zone adjacent to the plant site for future sludge disposal. Digested sludge was originally discharged after screening with the primary chlorinated plant effluent into Puget Sound. Although METRO studies have shown that this practice has no observable deleterious effects on the receiving water, this research program was initiated to comply with State and Federal direction to seek an alternative method of disposal. The research goal was to demonstrate the practicality of filling this diked area with sludge as a means of sludge disposal and land reclamation. Practicality was interpreted as being economically feasible and environmentally acceptable. For this project, consideration of disposal



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off site was not permitted by the funding agency, although some attractive alternatives are identified in the conclusions of this report.

The West Point plant provides primary treatment of sewage from a combined sewer system. Settled sludge is fed to a three unit high rate digester system. During periods of high rainfall, the design peak wet weather flow of 325 mgd is exceeded. Peak flows up to 400 mgd have been successfully handled by the plant. Operation of the digesters under high flow conditions is challenging and the resulting digested sludge has a one to three percent solid content (weight). Improved operations have increased the digested sludge concentration to three to three and one half percent solids. The solids will normally contain about 50 percent volatile material, but the non-volatile content will increase during periods of high rainfall when sediment from the combined sewers enters the system. During the demonstration period approximately 25 tons per day of dry digested solids were produced (approximately 200,000 gpd of three to three and one half percent solids digested sludge). Since the plant site is adjacent to the beach, large quantities of beach sand are available for use in the fill project. Figure 1 is a photo of the West Point site showing the diked area.

In 1965, METRO prepared a report (1) indicating that the current cost of $2.34 per dry ton of sludge disposed by discharge into Puget Sound could rise as high as $50 per ton if vacuum filtration, composting, or incineration were employed as sludge disposal alternatives. Even hauling to landfills would increase disposal costs to $17 per ton. Since the METRO budget is $10 million annually ($7 million debt service and $3 million operation) a cost of $50 per ton for 50 tons per day of sludge would create a cost of almost $1 million per year for sludge disposal. What would be more serious is that the sludge disposal processes are operation-intensive and the bulk of the sludge costs fall in the operation category. This would mean that the operations budget would increase by one-third and a major part of the operations of METRO would be devoted to sludge disposal. On the other hand if a capital-intensive system were employed, the operation (staff, administration, etc.) would see little impact, but a major capital item would be created. As part of the initial feasibility study an economic assessment was made to verify these earlier conclusions and indicate economic alternatives. These costs estimates are summarized in Figure 2 and are consistent with the initial assessment.

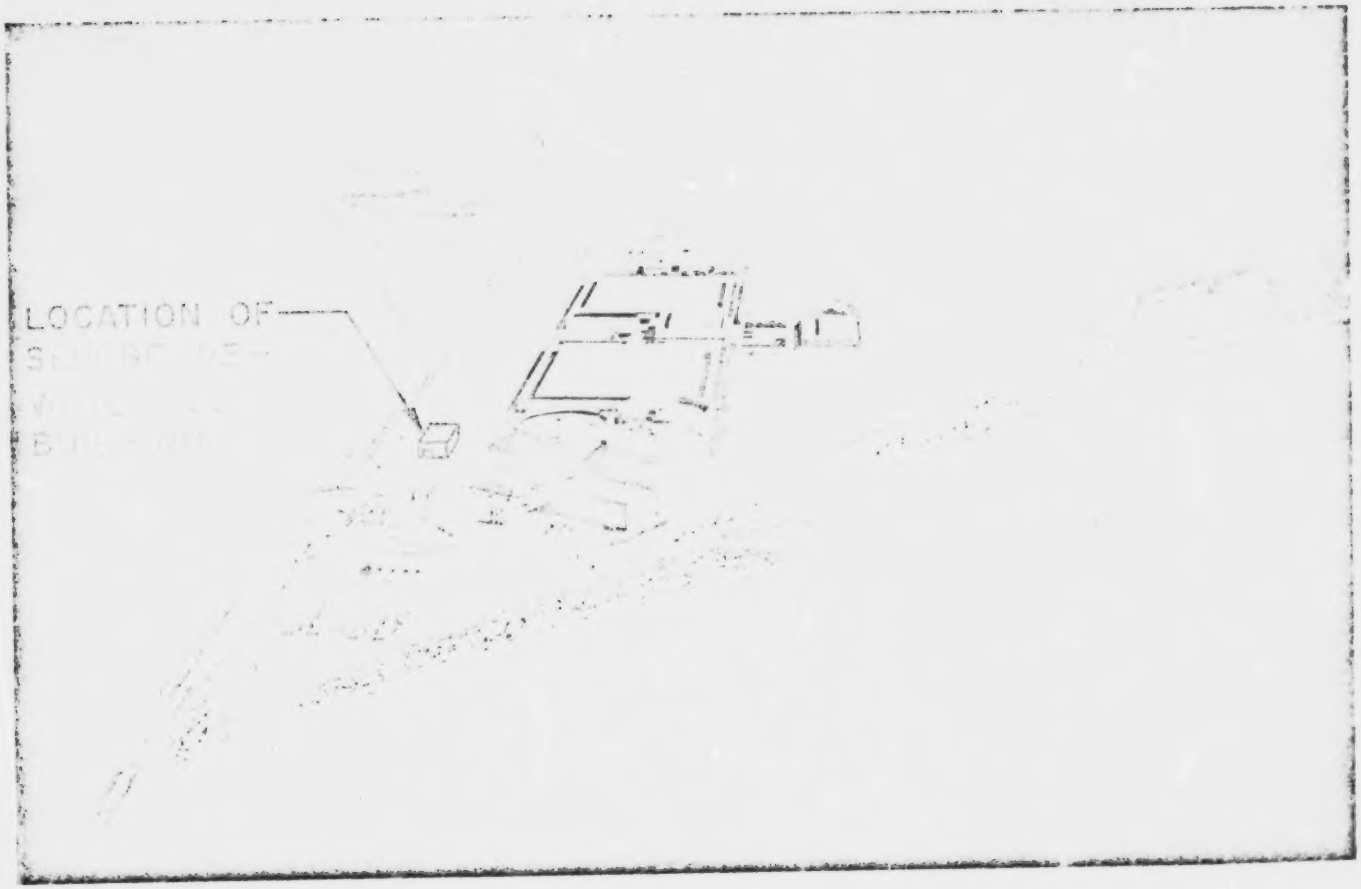


Figure 1. WEST POINT PLANT

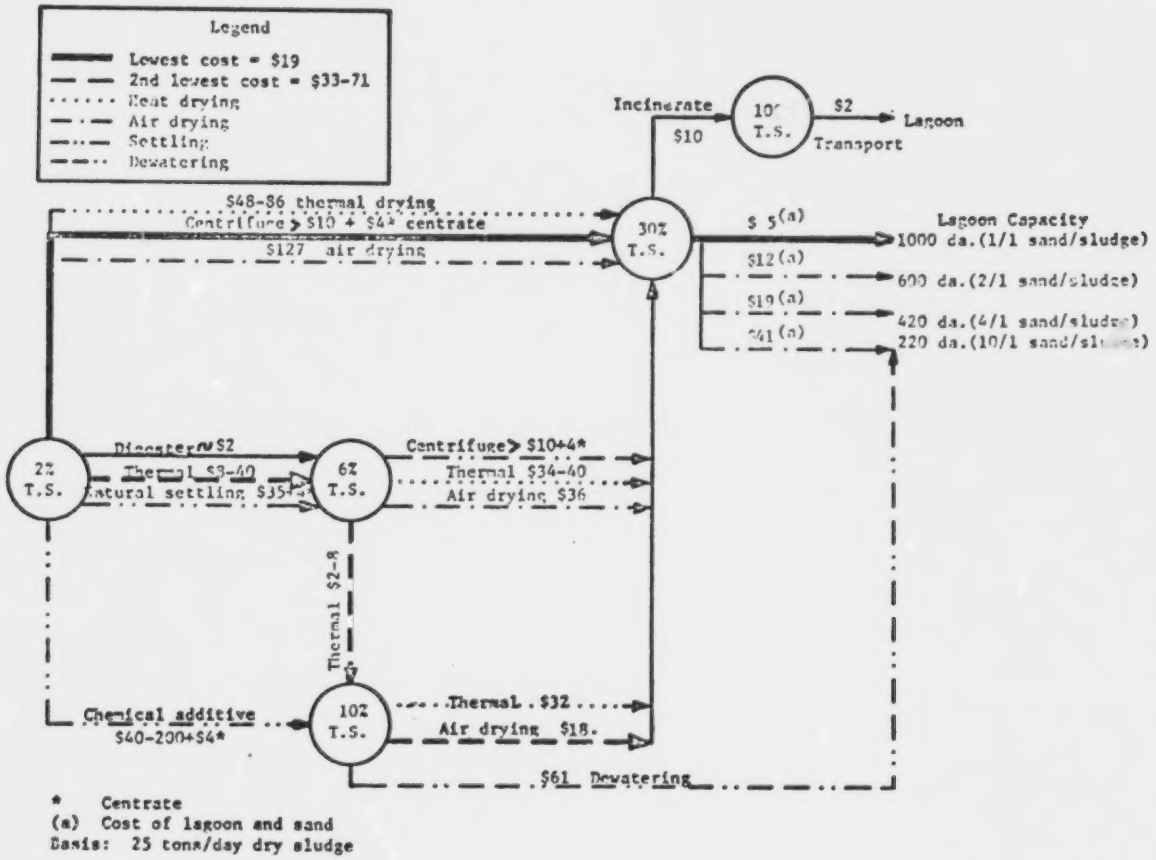


Figure 2. 1968 Estimated Disposal Cost per Ton of Sludge.

This final report contains the results of four research and development programs that were conducted serially. Each of these research programs were documented under separate cover and have been published as the research has been completed. (2, 3, 4, 5, 6, 7, 8) This report attempts to summarize the significant results and conclusions of these studies. The strategy of this demonstration project has been to conduct feasibility studies prior to each major demonstration activity. Thus the activities of the project become more specific and larger in scale with each iteration. The first research program was initiated in the summer of 1968 to demonstrate with laboratory scale experiments the critical problems and the feasibility of the proposed concepts. The second research program employed bench scale experiments concerned with pollution, drying and settling of the sludge. Bench scale research employed sludge samples up to one cubic yard. At the end of these two test programs a full scale sludge dewatering facility was designed and constructed. This facility provided a larger scale capacity to demonstrate project feasibility. The third research program in this series employed truck load samples and these results form the basis for the conclusion presented. The fourth research program of full scale field demonstration has only been in progress six months and significant results have yet to be obtained.

## SECTION IV

## LABORATORY STUDIES

Laboratory feasibility studies were initiated in the summer of 1968 to explore the removal of water and the addition of sand to sludge to create acceptable fill characteristics. To answer the question of fill stabilization, tests were designed to determine compressibility characteristics of potential fill mixtures. The environmental investigations were limited to the exploration of the water balance at the fill site and a literature review.

Initially there was hope that addition of sand to the digested sludge (1-3 percent solid content) would promote the clarification and settling of a dense sand/sludge mixture suitable for fill. These hopes were immediately destroyed when the initial experimental results revealed that sludge with solid content of less than ten percent would not produce a homogenous mixture with various types of sands. Instead a layer of sand would form with a layer of sludge on top. This eliminated all plans to study mixing of sludge and sand without prior dewatering of the sludge.

Recovering from this setback, the research centered upon the methods of dewatering digested sludge. Ignoring the existing literature that indicated that this was an art, and an expensive one at that, a series of experiments were made to stew, boil, freeze, and abuse the sludge in every possible way. Elutriation, coagulation, and other dewatering techniques were investigated with the general conclusion that none of these methods could produce a sludge with more than about ten percent solids content. Chemicals were added in the form of sea water, sulfite waste liquor, and commercial flocculants. Over 26 chemicals were tested individually and in combination, with the conclusion that large dosages were required to obtain a noticeable effect, and that the results were very sensitive to the daily changes in sludge characteristics. Nakamura (5) examined both coagulation-flocculation and air flotation of this sludge. These dewatering studies provided little encouragement that gravity settling should be employed. Such methods require either high chemical or process cost or large investment for settling equipment while still yielding a product which required extensive treatment before use as a fill material.



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The laboratory testing of dewatering methods indicated the following results:

A. Natural settling would yield a sludge with only 10 percent solids and would require many days resident time. Both foaming and gas production were encountered.

B. Chemicals could be added to settle the sludge but the results were highly unpredictable and the costs of chemicals would range from $14 to $180 per ton.

C. Seawater elutriation of sludge produced about the same dewatering of the settled sludge, but created about five times as much supernatant for disposal.

D. Sulphite waste liquors in concentrations between 2 and 30 percent had no significant impact on sludge settling.

E. Adjusting pH to 1.4 and refluxing for 24 hours improved settling but not solids content of sludge.

F. Freezing improves settling but not dewatering.

A complete discussion of these tests is reported in Reference 1.

The direct application of the dilute digested sludge to a beach area was investigated. This flood and tilling operation was found to be unsuitable for this project because of the large surface area required and the problems created by precipitation. Since the project was limited to the plant site, no suitable area was available for utilization of the method. The large amount of rainfall in the Seattle area created drainage problems and caused miring of mechanical equipment required for this technique.

The experimental application of one quarter inch (0.046 $lb/ft^2$), one half inch (0.092) and one inch (0.184) of wet sludge produced plugging in plots where the application exceeds one quarter inch per day. Based on this result, at least one acre per ton of sludge would be required for this type of disposal (50 to 100 acres total).

The preliminary studies of the characteristics of the fill materials indicated that the sludge fill must contain at least 20 to 30 percent solids on a wet basis prior to mixing with sand. The compressibility characteristics of a sand/sludge fill will not be affected by the source or type of sand available for this study. For comparative

purposes, the four to one mix approximates a moderately firm sandy silt, the two to one mix approximates a moderately firm clay silt, and the pure sludge approximates a moderately soft clay or moderately firm peaty silt. (3)

The tests also indicated that the water content of the fill (2/1 sand/sludge) must be reduced to less than 30 percent (dry basis) if placement and compaction is to be with mechanical equipment.

Because of the difficulty of dewatering and/or drying the sludge, these data suggested the placement of the mixture with little or no compaction and then to consolidate by use of a preload or temporary sand fill. A complete report of these compaction tests using the standard AASHO Method of Compaction is found in Reference 3.

Figure 3 indicates that at the optimum fill density a pure sludge fill would contain equal parts of sludge and water, and that the moisture content at maximum density will decrease as sand is added.

The apparent alternatives were to employ drying beds or to consider mechanical dewatering techniques. Based on information available at that time for capital and operating costs of various alternatives, the following recommendations were made:

1. Mechanical dewatering using a centrifuge is required and should be considered for the streams entering and leaving the digester. Treatment of the effluent from such an operation would be necessary to satisfy environmental constraints.

2. The cost of the seawall to contain the fill is a major capital investment and would raise the disposal costs to the level where off-site disposal alternatives should be investigated.

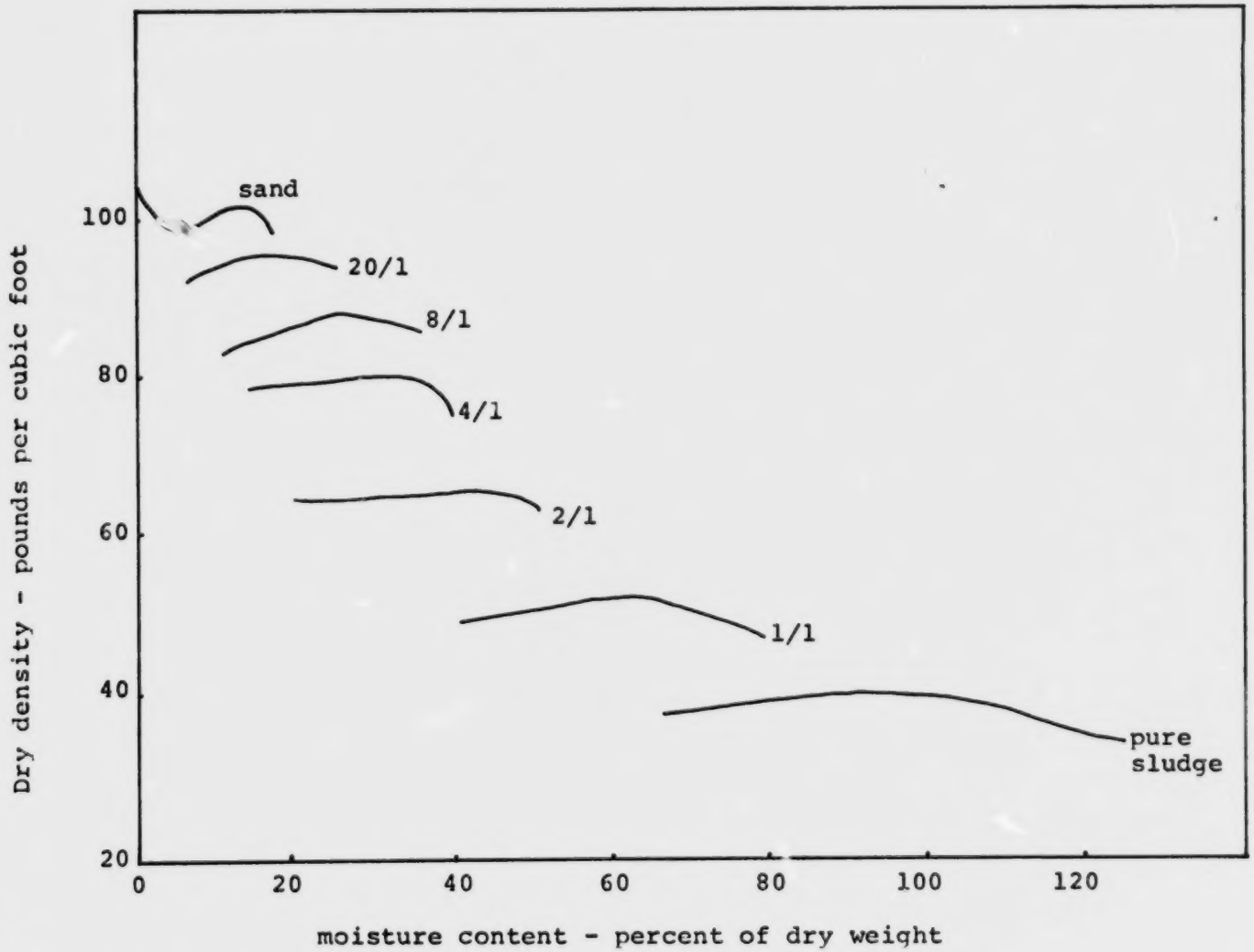


Figure 3. Standard AASHO Compaction Test Results
West Point Sand/Sludge Mixture

## SECTION V

## BENCH SCALE STUDIES

The project management decision after a year of study was to retain the on-site disposal constraint and to employ mechanical dewatering. These decisions provided the constraint for further investigation to concentrate on the study of handling of the centrate and solids from the dewatering operation, and the evaluation of the environmental impact of such a system. In order to provide an indication of the problems and characteristics of centrifuging digested sludge, a total of 20,000 gallons of digested sludge were transported to the Miller Creek Sewage Treatment Plant of the Southwest Suburban Sewer District. A 24 x 38 inch Bird centrifuge operating at 1800 rpm and a 30 gpm feed rate was available at this location. Runs are made in July, August, November, February, and April to produce sludge cake and centrate for use in the bench scale studies. No evaluation of chemical treatment of the digested sludge during the centrifuging process was possible with this equipment. The sludge cake solids content varied from 30 to 50% (wet basis), but the centrate contained a large fraction of the volatile solids, while most of the non-volatile solids appeared in the sludge cake. Typical characteristics of these streams are shown in Table I. Knowledge of the high volatile content of centrate initiated a series of studies to define alternative methods of controlling this problem.

In addition, these pilot studies explored the natural drying of sand/sludge mixtures, the consolidation of sand/sludge mixtures, the pollutional aspects of the fill operation, and a continued search for innovative solutions. In these studies the basic questions were to determine whether to dry the fill material prior to consolidation or combine the drying and consolidation process. The parameters of interest were the time elapsed prior to use of the fill for a park and the cost required for placement and settling of the fill.

### DRYING

The drying of sand/sludge mixtures was reported by Harper (4) for samples in containers 6 to 18 inches in diameter and 6 to 12 inches deep. A design equation was developed for sand/sludge mixtures employing per cent saturation as the variable:

TABLE 1: CHARACTERISTICS OF SLUDGE CENTRIFUGE STREAMS

Miller Creek Run

| | Digested Sludge Feed | Sludge Cake | Centrate |
|---|---|---|---|
| Total Solids, % of net wt. | 2.25* | 28.7 | 0.67 |
| %s of Dry Solids: | | | |
| Total Volatile Solids | 45 | 32.2 | 71.9 |
| Ash | 55 | 67.8 | 28.1 |
| Hot Water Solubles | 8.9 | 4.2 | 25.6 |
| Alcohol Solubles | 9.6 | 4.2 | 25.1 |
| Ether Solubles | 5.4 | 2.5 | 10.7 |
| Crude Protein | 9.7 | 7.0 | 20.6 |
| Total Nitrogen, mg/l | 30,025 | 12,935 | 79,164 |
| BOD, mg/l | 2,385 | - | 2,160 |
| Total Coliform: | | | |
| MPN/100ml | $2.4 \times 10^7$ | | $1.5 \times 10^7$ |
| MPN/gm net weight | | $2.4 \times 10^6$ | |
| Fecal Coliform: | | | |
| MPN/100ml | $9.3 \times 10^6$ | | $2.3 \times 10^6$ |
| MPN/gm net weight | | $4.3 \times 10^4$ | |

* Solids typical for 1968-69, current solids content of feed 3 to 3 1/2%.

$$\text{Drying rate} = (-0.022 + .00022\,(RH) + .000688T - 6.88 \times 10^{-6} RH \cdot T)S \text{ lbs/day/ft}^2$$

where RH is the drying air relative humidity (percent), T is the drying air ambient temperature, °F, and S is the percent saturation moisture content. The design equation was found to be accurate within 40 percent, and required only the temperature of the air, and the ambient relative humidity of the air, and the percent saturation for prediction. There was no significant effect due to sand concentration in the mixture for sand/sludge ratios as high as 20/1. Mean drying rates for the West Point location were found to be less than three tenths of a pound per square foot per day. Assuming that a cubic foot of centrifuged sludge cake contains 40 pounds of water, at least one half year per foot of fill depth would be required to air dry the fill to the optimum density moisture content. Although no effect of depth on drying rate was observed in this series of tests, no data were obtained for depths greater than one foot. Since air drying is a surface-controlled phenomenon, the drying rate is the same for all depths.

The design equation was developed from 77 experiments conducted from July, 1968 to December, 1968 using various sands, sludges, and sand/sludge ratios. A separate series of tests was conducted in March, 1969 after the design equation was derived, to verify the design equation. The mean error between these data and the predicted results was 41 percent. The major source of error was traced to the use of Seattle-Tacoma Airport weather data for conditions at the University and at the West Point site.

The following procedure has been developed to aid the design engineer in determining when the mixture moisture content has been reached such that maximum density may be achieved.

1. Choose the sand/sludge ratio for the fill material as required by soil density specifications.

2. Conduct a total solids test on the mix and calculate the initial moisture content.

3. Determine the mix saturation moisture content and calculate the percent saturation for the mix.

4. Using recorded weather data, calculate the average temperature and relative humidity for the drying period.

5. Calculate the average drying rate from the design equation.

6. Multiply the drying rate times the drying mix surface area and drying period to obtain the weight of water evaporated.

7. Subtract the weight of evaporated water divided by weight of dry solids from initial moisture content to calculate the new average moisture content of the mix.

This method can be used to estimate when the mixture moisture content for maximum dry density has been reached. Periodic calculations will determine to what stage on the dry density-moisture content curve the mixture has dried.

The design equation is also applicable to sludge drying on sand beds provided that the sludge is in the falling-rate period. For drying in the constant-rate period, equations describing evaporation of pure water may be used up to the critical moisture content.

Determination of drying area requirements is a third application of the design equation. The initial and desired final moisture contents, their corresponding percents of saturation, and average weather conditions for the drying period must be known. The equation presents a quantitative description of drying bed performance to allow comparison with performance of mechanical, chemical, or physical processes to dry sludge.

SETTLEMENT

A parallel study was conducted by Cameron (3) to determine the settlement of sludge in a deep fill. A comprehensive search of the literature indicated that no studies of this type have been published. The purpose of Cameron's study was to establish a method that would permit the prediction of sludge fill settlement from laboratory load controlled tests using an Anteus Model A-1 consolidation machine. The available theory of the consolidation of soils, the theory of vacuum filtration and filter pressing, and the literature on consolidation of peats were synthesized into a theory for sludge settlement. Field experiments were conducted in containers (16 square feet of surface area and two and four feet deep) to simulate semi-infinite extents of sludge.

The parameters related in the theoretical analysis were the compression of the sludge, the excess pore pressure, and the Terzaghi time factor. Differential equations were formulated for continuity and vertical equilibrium in the sludge mass. A computer program was formulated to provide a finite difference solution of these equations. Load controlled labora-

tory tests were designed to develop the constants describing the sludge characteristics necessary in these equations. One of the significant theoretical results of this study was a development of strain rate controlled laboratory tests which could provide the constants for these equations at low costs and faster than the load control tests. The theory and computer analysis have been reported separately in Reference 3.

In order to provide a rapid means of developing design criteria for proposed sludge landfills, empirical formulations have also been developed for predicting settlement and time of settlement for sludge with moisture contents of about 250 percent (dry basis). The prediction of settlement is based on a rational examination of the relationship between void ratio and initial moisture content and an empirical relationship between final moisture content and applied load. In these determinations no account has been taken of volatile solids reduction, nor of gas production. Furthermore, the sludge is considered to be completely saturated. Based on the results from field tests the equation developed for settlement is:

$$4.94 - \log p = \frac{Gw_o}{100} - \left(\frac{Gw_o + 100}{100}\right)\frac{\Delta H}{H}$$

where p is the load applied plus one half the area dry weight of sludge (psf), $w_o$ is the moisture content of the sludge (percent dry basis).

A value of 2.14 for G was found to be relatively consistent in this research. Thus, knowing the applied load and the initial moisture content the ultimate settlement of the fill can be determined.

An equation for time of settlement was also developed on a rational basis using the same assumptions as above. In this development the variation in coefficient of consolidation was related to the initial moisture content and then inserted into the Terzaghi time factor equation. This resulted in:

$$t_x = \frac{T_x H^2}{(1+w_o)\log^{-1}(6.22-4.22\ w_o)}$$

where $T_x$ is the Terzaghi time factor for any settlement to be predicted, and H is the original depth. Use $\frac{H}{2}$ if both top and

bottom drainage is possible.

Again, knowing the initial sludge moisture content and substituting the appropriate time factor it is possible to calculate the time required for any degree of settlement. Although the theoretical predictions are undoubtedly much more accurate, the use of the empirical equations will provide acceptable predictions of sludge landfill settlements and times of settlement.

Cameron's work indicated that sludge landfills would face problems of gas formation in the sludge due to the stabilization of organic materials. This may cause initial expansion of the fill and severely retard the rate of settlement of the fill in the early stages. The time of ultimate settlement, however, was not affected to any marked degree by this gas production. In large scale fills, however, it is possible that extended periods of gas production may cause increases in overall settlement times. The reduction in volatile solids content due to biological action can significantly affect the magnitude of the total settlement. In one case, where the sludge used was in a highly active state of degradation, volatile solids were reduced from 26.75 to 20 percent in a 3 1/2 month period. The corresponding volume reduction was calculated to be nearly 4 percent of the total original volume. For the same type of sludge under the same loading conditions total strain in both laboratory and field tests was essentially the same. It was therefore concluded that the use of Teflon-lined consolidation rings in the laboratory reduced side wall friction sufficiently so that the frictional effects could be ignored. The initial moisture content of the sludge greatly influences the length of time required to reach any specified degree of settlement. The time for 90% settlement was reduced from 35,000 minutes (3 1/2 weeks) to 5,000 minutes (3 1/2 days) by placing sludge with 222 rather than 248 percent moisture.

## POLLUTION IMPACT

Benedict (2) evaluated the treatment of sludge centrate and environmental impact of a sludge fill using laboratory tests. These problems are schematically shown in Figure 4. The centrate from the centrifuge tests contained as much as one percent solids and a BOD as high as 3,000 mg/l. Studies of pretreatment of digested sludge by pre-aeration or chlorination prior to centrifugation yielded negative results. Addition of polyelectrolytes appeared to be effective, but

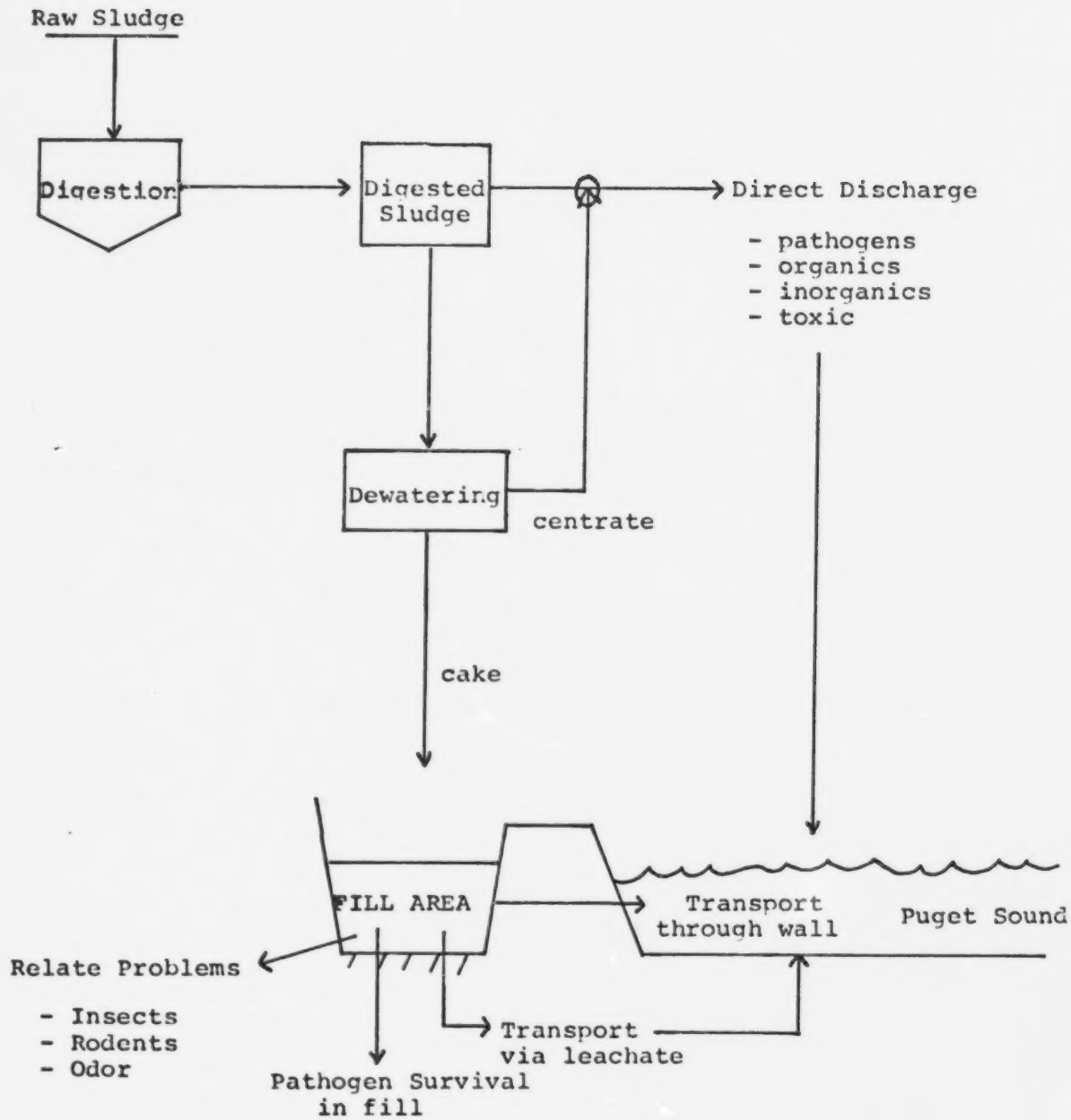


Figure 4. Pollution Aspects of Wet Digested Sludge Disposal.

the high cost of these chemicals may limit their usage. BOD concentrations in the centrate from chemically treated digested sludge could be reduced to 200 mg/l. If chemicals are not used, an extensive program of centrate treatment would be required.

Treatment of centrate by plain aeration was observed to require several weeks to obtain a 90 percent reduction of BOD. Both diluted and undiluted samples could be treated in this way. Treatment of the centrate with activated sludge was not successful unless the solids content of the centrate is low (about 0.5 percent). By diluting the centrate to a BOD of 1100 mg/l, and using a biological solids concentration of 2700 mg/l, a 50 percent reduction would be obtained in a day. Examination of chemically treated centrate indicated that further treatment by biological methods is possible, and that these chemicals are not toxic to the activated sludge. Examination of the possibility of returning the centrate to the plant head works using laboratory settling tests were inconclusive. A survey of the literature and plant operators also provided conflicting opinion. If anything, the laboratory results indicated that lower removals would occur in the primary tanks if the centrate were returned.

A program of exploratory laboratory studies to examine the pollutional aspects of sludge fill was conducted to define direct environmental impacts of the fill. Routine sampling programs were established to obtain inplant coliform balances, background coliform data at stations near the lagoon, and grab sampling of raw sludge, digested sludge, centrifuge sludge cake, and centrate. The laboratory tests at 4° and 20° C of the coliform die-off rate in sludge cake indicated a rapid die-off for one or two months, followed by a slower rate between two and six months. Examination of potential regrowth in sludge samples stored for three months indicated that the sludge cake does not favor coliform growth even at the optimum coliform growth temperature of 35° C. Examination of a four foot deep column of sludge cake for seven weeks indicated an even distribution of coliform with no spatial distribution observed. When sludge cake was placed between two layers of sand, the coliform organisms were observed to be carried into the sand layer. Salmonella spp. were found in all samples tested, but virus tests were negative. An independent study of virus in sewage sludge was conducted as a separate research project by Prof. Hatlen at this University. The field stations established for coliform background studies were sampled to establish background.

The initial coliform measurements in the Sound reveal high levels that decreased as all raw sewage was intercepted by the METRO system. Four stations were also monitored using oysters as the concentration agent. The oyster coliform counts were found to be proportional to the water sample results, but vandalism was high at these oyster stations and the experiments were terminated.

The coliform results were limited in value since some pathogenic agents may survive longer than the coliform group under the conditions studied; the coliform group yields no information on the response of animal parasites; and the coliform group are not valid indicators of viral transmission in soil. An extensive sample and testing program for pathogenic bacteria, viruses, and animal parasites in the field is required before any conclusions on the pollutional impact could be established. Laboratory and small-scale test results cannot establish conclusively the impact of the fill on the receiving waters.

Laboratory experiments to determine the effect of chlorination of sludge prior to dewatering indicated poorer rather than better dewatering. Gravity settling and centrifugation were simulated in the laboratory using a 30-minute settling test and a 5-minute, 750 rpm spin in a laboratory centrifuge respectively. Chlorine concentrations ranging from 0 to 1,000 mg/l as ($OCl^-$) were tested using 1,000 ml beakers and a jar-test apparatus. Contact times of 15 and 30 minutes were compared and found to be insignificant. While dewatering is not improved by chlorination, the volatile solids in the supernatant were decreased significantly when dosage exceeded 500 mg/l $OCL^-$. The failure to improve dewatering was observed to be related to increased flotation of the particles due to gas formation (probably oxidation of organic matter). In hindsight, given the current knowledge that the sludge is active after dewatering, its chlorination may be necessary to prevent continued digestion and to reduce the coliform content in the sludge fill.

One basic question that must be answered prior to filling the diked area is whether any liquid would leach from the fill to the Sound. Study of the water movement in the fill site indicated that the net inflow of water into the diked area was from the land side, not from the sea water side. At high tide a 10 foot hydraulic head on the sea water side exists on the bulkhead, but the salinity in the diked area water was observed to be very low. The major leaching problem anticipated is fresh water drainage during the

rainy periods. These waters will be collected and returned to the plant.

The conclusion of the bench scale studies is that the fill should probably be accomplished using centrifuge sludge cake with 30 to 50 percent solids content (wet basis). The moisture in the sludge cake can be reduced by thickening the sludge from the digester, by modified digester operation, by proper operation of the centrifuge, and by the addition of chemicals to improve solids removal. The sludge cake should be placed in the fill in a deep layer and preloaded with a sand layer to promote consolidation. Once the fill is stabilized a layer of sand will be left on the fill to prevent exposure of the sludge to humans. These bench scale conclusions were the hypotheses that were tested in the pilot studies.

While the centrate problem was identified early in the feasibility study, the only other alternative at the time was to employ a filter rather than a centrifuge for dewatering. In 1969, filter technology was not as promising as the centrifuge technology, and the decision was made to design a centrifuge dewatering facility for this demonstration. In retrospect, the centrifuge has presented major maintenance problems which precluded operations that can produce a dry cake and a "clean" centrate. A filter is currently being designed to evaluate the other alternative dewatering mechanisms.

## SECTION VI

## DESIGN AND OPERATION OF PILOT DEWATERING FACILITY

### GENERAL CRITERIA

The West Point Centrifuge Pilot Plant was constructed as part of the "Park Development with Wet Digested Sludge" demonstration grant project. This phase of the project included the site preparation of the existing four acre sludge lagoon to receive the sludge fill and provide the necessary sand material at the lagoon site for fill mixture experimentation. Two separate contract documents were prepared by the Municipality's Engineering Division, one covering the centrifuge pilot plant, and another the sludge fill site preparation.

The contract for the plant facility was advertised for bids and awarded in May, 1970, and construction completed in March, 1971. The contract for the sludge fill site preparation was awarded in October, 1970, and construction completed in January, 1971.

The land reclamation with wet sludge project entailed four phases of development. The pilot sludge dewatering plant was designated as a separate phase in the original plan of operation. Design criteria and guidelines for the method of sludge dewatering operation were established from costs and laboratory investigations conducted by the University of Washington. The general design criteria were to recover 30 tons/day of dry solids from 200,000 gallons per day of digested sludge.

The Centrifuge Pilot Plant represents the first stage of an ultimate expansion for additional sludge dewatering facilities. The sludge centrifuge facility consists of a reinforced concrete frame building with a precast concrete panel exterior, which houses a single engine-driven 36 x 96-inch concentric bowl centrifuge and all necessary auxiliaries (see Figures 5, 6, 7, 8). The centrifuge is fed by a progressing cavity type positive displacement pump which is arranged to pump from any one of the plant's three anaerobic digesters. Centrate is discharged to a sump and then pumped to the plant's submarine outfall. An electric motor-driven helical distributor transports dewatered sludge to the inlet of an open-throat progressing cavity-type positive displacement pump. This pump discharges to a truck loading area where the solids are trucked from the centrifuge facility to the nearby lagoon. The material is either deposited in specially constructed research cells or into a general fill site.

The exterior of the building (see Figure 7) has followed the

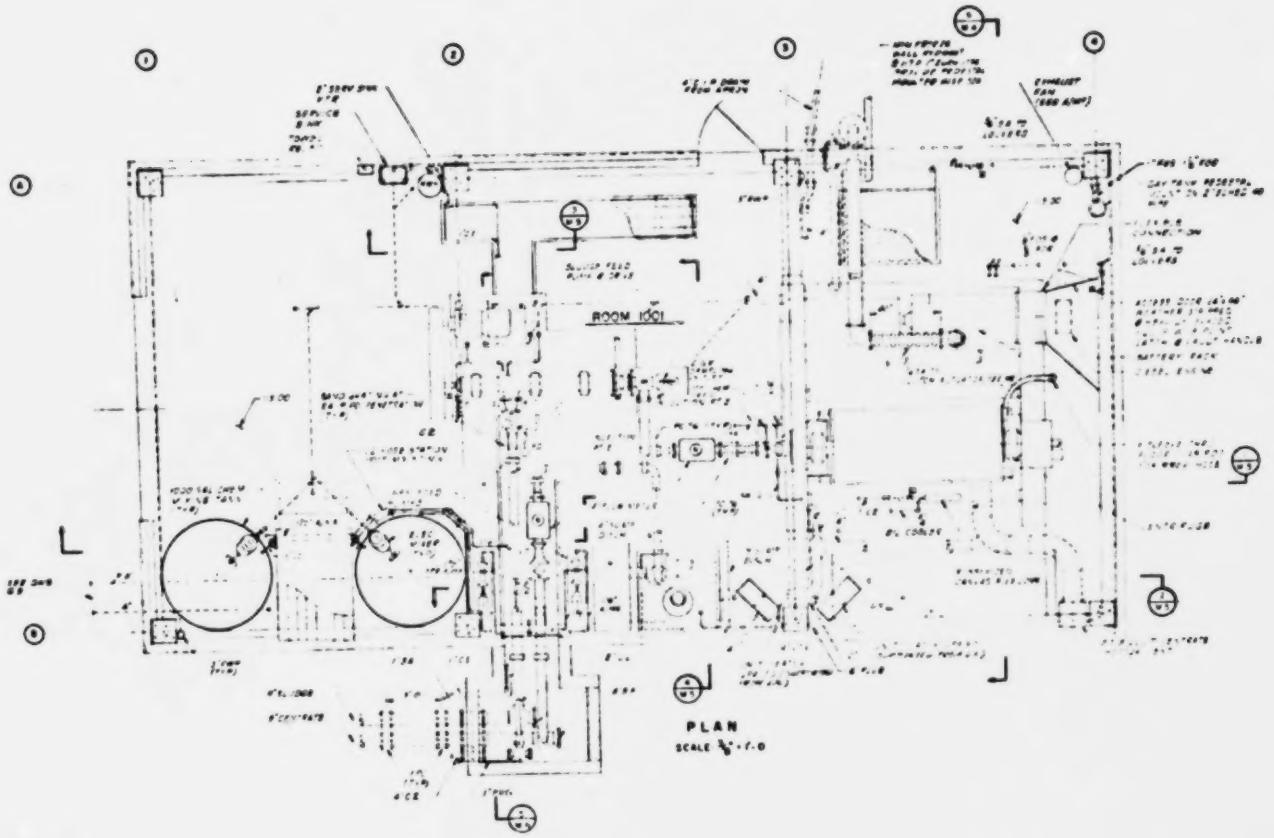


Figure 5. PILOT SLUDGE DEWATERING FACILITY
plan view

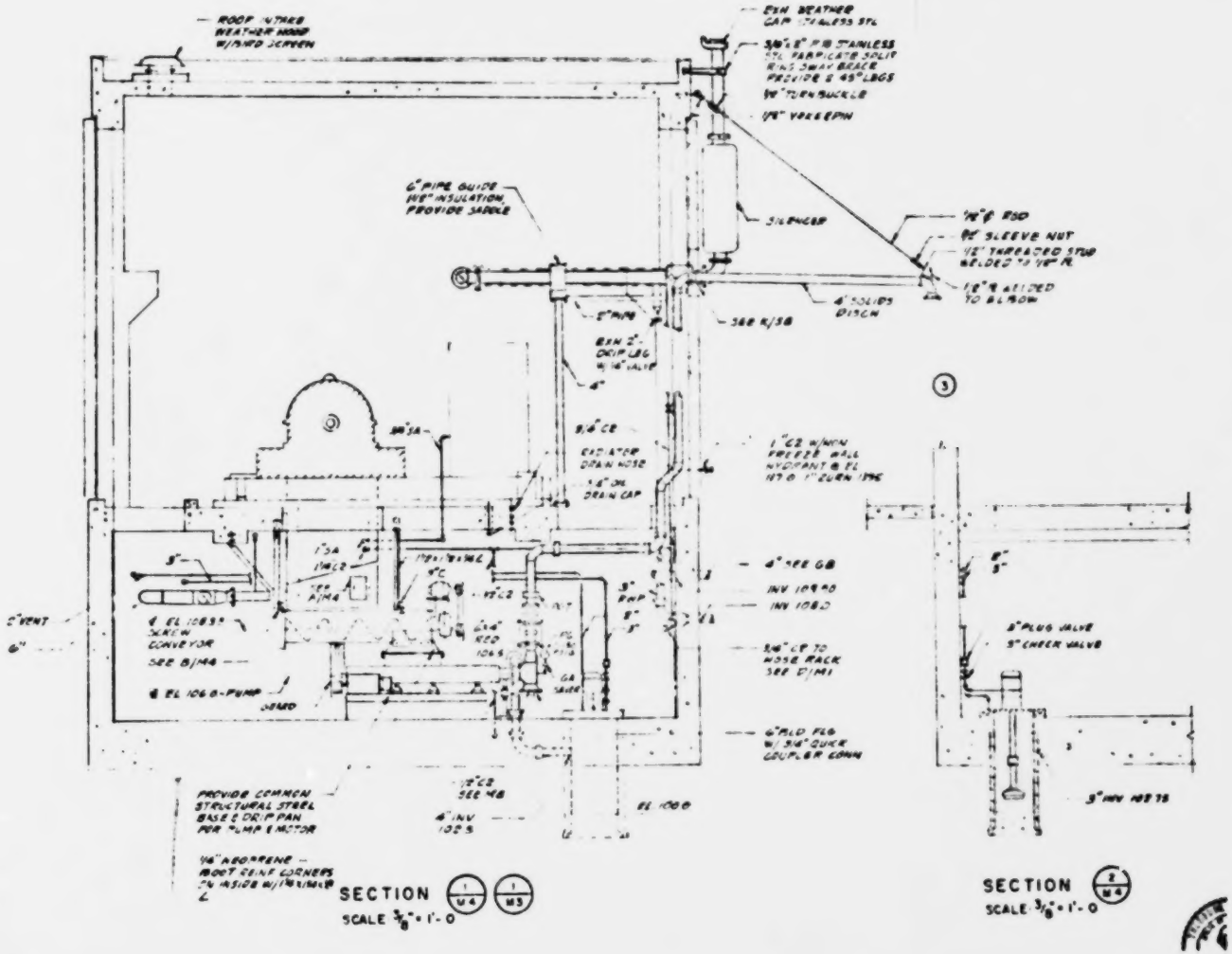


Figure 6. PILOT SLUDGE DEWATERING FACILITY
elevation view

Figure 7. CENTRIFUGE BUILDING

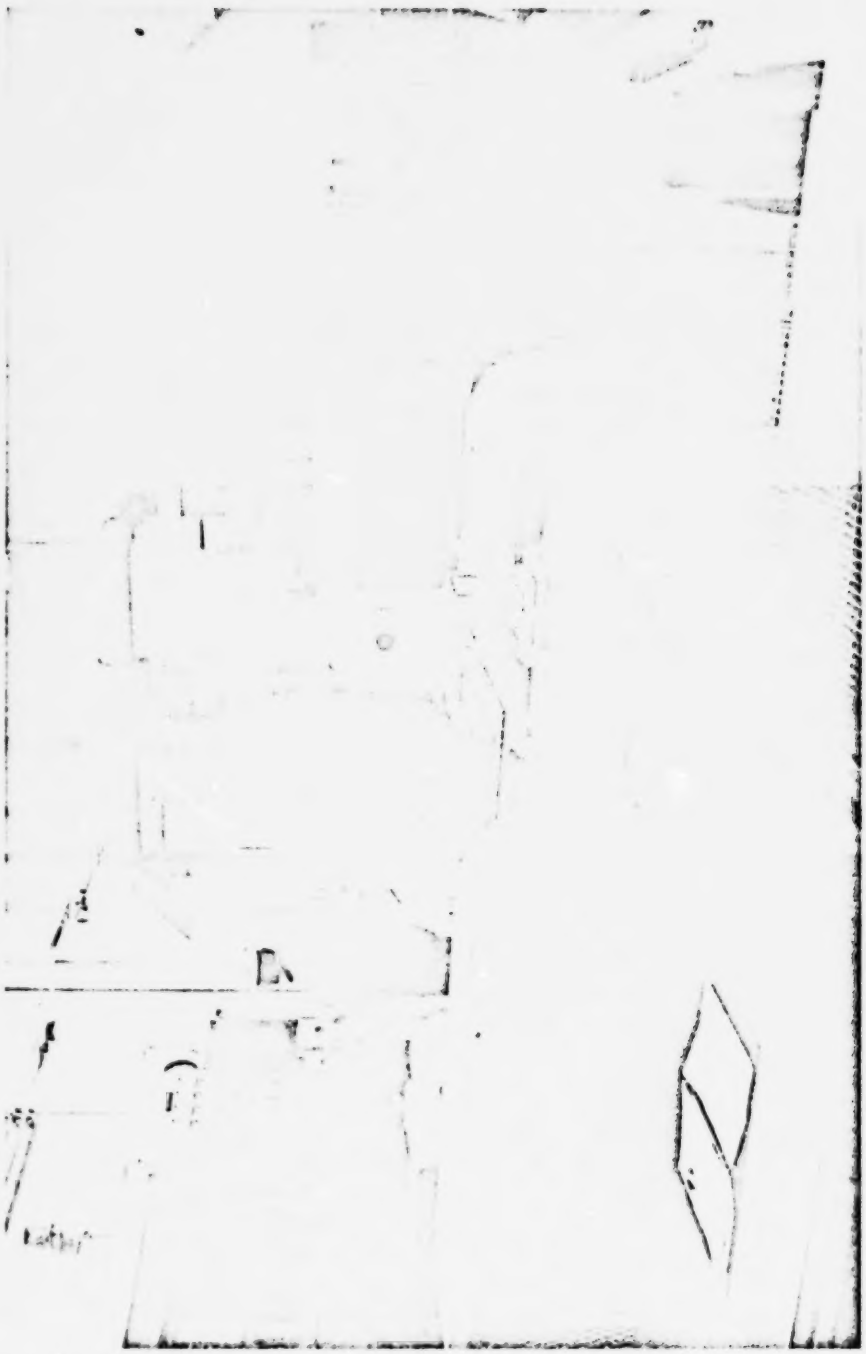

Figure 8. INTERIOR OF SLUDGE CENTRIFUGE FACILITY

standard exterior requirements set forth in the original design of the West Point treatment plant. Construction provides for expansion when future requirements for sludge dewatering exceed the present capacity. Among the expandable features are (1) corbels for a bridge crane that will eventually extend through the entire length of the building, (2) knock-down concrete blocks in the east wall of Room 1002 and in the pipe chase outside the south wall of Room 1001 and (3) concrete columns designed for future expansion. Although Room 1002 is not classified as an area of hazardous conditions, all electrical and ventilating devices are either explosion-proof, vapor tight, or spark-proof.

Delivering treated, digested sludge from the screening building to the pilot plant for dewatering is the basic flow pattern. All liquid products except the cake are then returned to the screening building by the centrate pipeline. All building waste water is piped to the building sump in Room 1002 and into the treatment plant outfall via the centrate sump.

The potable waterline extends from the screening building to the pilot plant to supply the hot water tank and the cold water for the service sink. Compressed air is also supplied from the screening building to operate the louvers and provide emergency air to operate the clutch and disengage the centrifuge from the diesel. The water for flushing and chemical make-up water is furnished by a new 6-inch pipeline from the front of the administration building.

The sludge feed pump speed is varied by a manually operated hydraulic drive unit. The drive unit has a maximum speed of 1750 rpm. The normal output of the pump is 300 gpm @ 30 psi when rotated at 350 rpm and its maximum speed is 475 rpm. This limitation prevents overloading the centrifuge. The feed rate must be adjusted in conjunction with the solids handling capability of the centrifuge and the sludge cake pump.

The sludge centrifuge is a horizontally continuous solid bowl unit specifically designed for dewatering digested sludge (see Figure 8). It is a 36" by 96" unit capable of handling a maximum digested sludge feed at 400 gpm at a consistency of 1.5 to 6 percent solids by weight. The centrifuge operation can be described as a high rate mechanical clarifier in which the effluent or centrate is skimmed off one end of the machine and the sludge is moved towards the other end by a conveyor similar in operation to a clarifier flight. The relative motion between the conveyor and the bowl is accomplished by means of a planetary gearing system. Flocculant aids are added through chemical feed ports within the centrifuge.

The prime mover is a 250 horsepower, turbocharged four stroke cycle, water-cooled, compression ignition, overhead valve, open combustion chamber, direct injection diesel engine. The unit is equipped with an inter-cooler for cooling air from the turbocharger before it enters the cylinders. The engine is set to idle at 700 rpm. The no load rpm is set at 1600 and the full load rpm set is 1500 rpm. Normal running speed is 1500 rpm. The engine output at 1600 rpm under sustained load is 260 brake horsepower.

The engine is connected to the centrifuge by a mechanical clutch, which in turn drives a hydraulic fluid coupling. An eight grooved sheave is mounted on the output shaft of the fluid coupling. Eight belts are then utilized in driving the centrifuge. The speed of the engine is controlled by a hand throttle on the engine.

The dewatered (cake) sludge equipment consists of an electric motor-driven helical distributor which in turn transports the cake into an open throat progressing cavity type positive displacement pump which discharges through piping to an outside truck loading one to the north of the building. The helical distributor is a screw conveyor unit with a 12-inch diameter ribbon flight conveyor and is rated to move 400 cubic feet of dewatered sludge per hour. It is driven at constant speed by an electric motor. The cake pump has a capacity of 40 gpm of dewatered sludge at 200 rpm with a discharge pressure of 95 psi and is controlled by a rheostat that will increase or decrease the motor speed as required.

The pilot plant has been equipped with a mixing and a dilution facility for chemical preparation. The facility consists of two 1,000 gallon fiberglass concentrated chemical storage tanks, two portable chemical mixers, two variable speed progressing cavity type positive displacement metering pumps, two rotameters, and chemical eductors.

The chemicals are generally mixed in the storage tanks and metered by the positive displacement variable speed pump. The maximum capacity of the pump is ten gpm with a one gpm lower output regulation limit. The pump is controlled manually by varying the output speed of a Varidrive unit between the pump and motor. The piping for chemical solution addition is designed so that chemicals can be introduced upstream of the sludge feed pump or directly into the centrifuge.

The centrifuge pilot plant has been equipped with all necessary waste handling piping and equipment consisting of a building sump pump and a centrate sump pump. The building sump pump is

an electric motor-driven constant-speed vertical submersible pump, with extended drive shaft to pedestal mounted motor. Its pumping capacity is 100 gpm @ 25 feet of head and is controlled automatically by a float mounted in the sump. The bulk of the fluid pumped is the centrate underdrain from the centrifuge. This pump also handles the discharges to the loading apron catch basin.

PLANT OPERATION

It requires two men to operate the system. One man attends to the centrifuge while the other loads trucks and hauls sludge cake to the test cell, as shown in Figure 9. With modification to the centrifuge installation, it is anticipated that one man could accomplish both functions.

In an eight-hour shift, approximately six and one-half hours of operation are realized; the balance is required for start-up, flushing and cleaning operations. Extended flushing is required to minimize vibration caused by material buildup in the centrifuge.

Maintenance of the centrifuge system for approximately 600 operating hours totals 658 hours for repair and adjustment. Repair parts cost $1,775 or approximately $3.00 per hour of operation. The bulk of the repair is associated with wear caused by silt in the sludge.

Based on experience to date, it appears that an output of four tons per hour of sludge containing 50 percent solids is possible. Using the two tons of dry solids per hour for a cost base the cost per dry ton is as follows:

| | |
|---|---|
| Facilities - straight line 10-year depreciation | $ 5.50 |
| Fuel and lights | 1.00 |
| Parts and material | 1.50 |
| Labor at $10 per hour | 15.00 |
| Total cost per dry ton placed in the test cell | $23.00 |

This cost does not reflect chemical costs for centrate treatment nor for backup equipment to provide reliability.

The centrifuge is diesel powered because it was originally intended to operate on the fill site. This configuration is not desirable as a permanent installation because of the noise and maintenance costs associated with the diesel. Additional labor is required to maintain the cake pump and pump room which were added to adapt the portable centrifuge to a fixed installation. Based on our experience, future design can reduce the cost per dry ton of output as much as 50 percent.

Figure 9. DEWATERED SLUDGE LOADING

The sludge cake is transported from the centrifuge to the test cell in dump trucks (see Figure 10). This has created no special problems other than some loss around the tailgate and traction problems in wet weather. All-wheel drive units would be an advantage.

Initial testing on centrifuge dewatering efficiency was begun in March, 1971. This was done without chemical aids to evaluate machine performance at different control settings. Those settings selected were: Bowl speed of 1400 rpm, sludge feed rate of 300 rpm and pool setting of three inches. This was a compromise between the driest cake and the best quality centrate that could be obtained. Equipment life and maintenance were also important considerations in selection of these settings.

Serious testing with chemical dewatering aids was begun in June, after a number of polymers were screened in the laboratory. During laboratory testing, some analytical problems required us to make adjustments in data calculations.

Several methods were tried to obtain consistent results on sludge "suspended solids". None of these was successful, so "total solids" was used in mass and cost calculations. This parameter tends to make solids recovery and polymer cost a little lower. However, one can still evaluate relative merits of the polymers tested. The best polymers, of those tested, were Nalco 610, Hercules 814, and Hercules 810. They produced solids recoveries of 84, 94 and 84 percent, respectively. Dosage rates and costs for this kind of performance are high for this application, exceeding $50 per ton of sludge for chemicals.

Pool setting made a significant difference in solids recovery, as expected. A much wetter cake is always the result of high pool settings. If very high solids removal (90 percent plus) is desired, then one must pay the price of wetter cake in this kind of dewatering method.

Comparative tests to evaluate the points of chemical addition were attempted, but judgement on these points (at centrifuge pool or ahead of sludge feed pump) is difficult to make. Varying amounts of dilution water through the Calgon-Nalco-Hercules tests confuse the significance of where polymer is injected.

Polymer tests that are being run in 1972 indicate that the sludge feed pump may smash some of the flocs, and that most additions of chemical at the centrifuge will produce the most efficient solids capture. Data on these tests is not yet complete.

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Figure 10. SLUDGE FILLING OPERATION

Investigation into high molecular weight, cationic polymers, or cationic-anionic polymer combinations, is continuing.

## SECTION VII

## PILOT FIELD TESTS

Delays in the design and construction of the dewatering facility created time constraints that threatened the completion of this project prior to the deadlines for sludge discharge termination established by the regulating agencies. The production of large amounts of dewatered sludge was not possible until the spring of 1971. Since filling of the lagoon would require at least two years, there was no hope of obtaining full scale field data prior to the termination of this project or prior to the deadline to terminate sludge discharge to the Sound.

In order to accumulate the maximum information in this limited time, a program of pilot field tests was established employing cells approximately 50 square feet in area and ranging between two and ten feet in depth. Some of these cells were constructed so the entire cell could be weighed continuously to observe moisture losses. Instrumentation was placed to record moisture content, temperature, and settlement. Sampling devices were used to collect samples of leachate and sludge.

The purpose of these pilot field tests was to verify the laboratory and bench scale results and to identify scale-up problems not revealed by the smaller experiments. The major test objectives were to verify the settlement predictions, to test the impact of vegetation on sludge dewatering, and to observe the pollutional impacts of the sludge fill. Filling of the full scale lagoon began in the summer of 1971 and preliminary results from this operation are reported in Section VI.

### SETTLING CHARACTERISTICS

Observations of dewatered sludge behavior in a 10-foot diameter cylinder supported the predictions of Cameron. Differential rates of settling were observed in the deep fill, with the lower zones settling more than the upper zones expressed as percentage of strain. The higher permeability and short drainage distances in the lower zones, plus the increasing effect of its weight contribute to the higher settling rates near the bottom of the fill. Typical settling data is shown in Figure 11.

A series of experiments exploring the load-bearing capacity of dewatered sludge in a deep fill indicated that this wet sludge acted as an uncompressible fluid. It was necessary

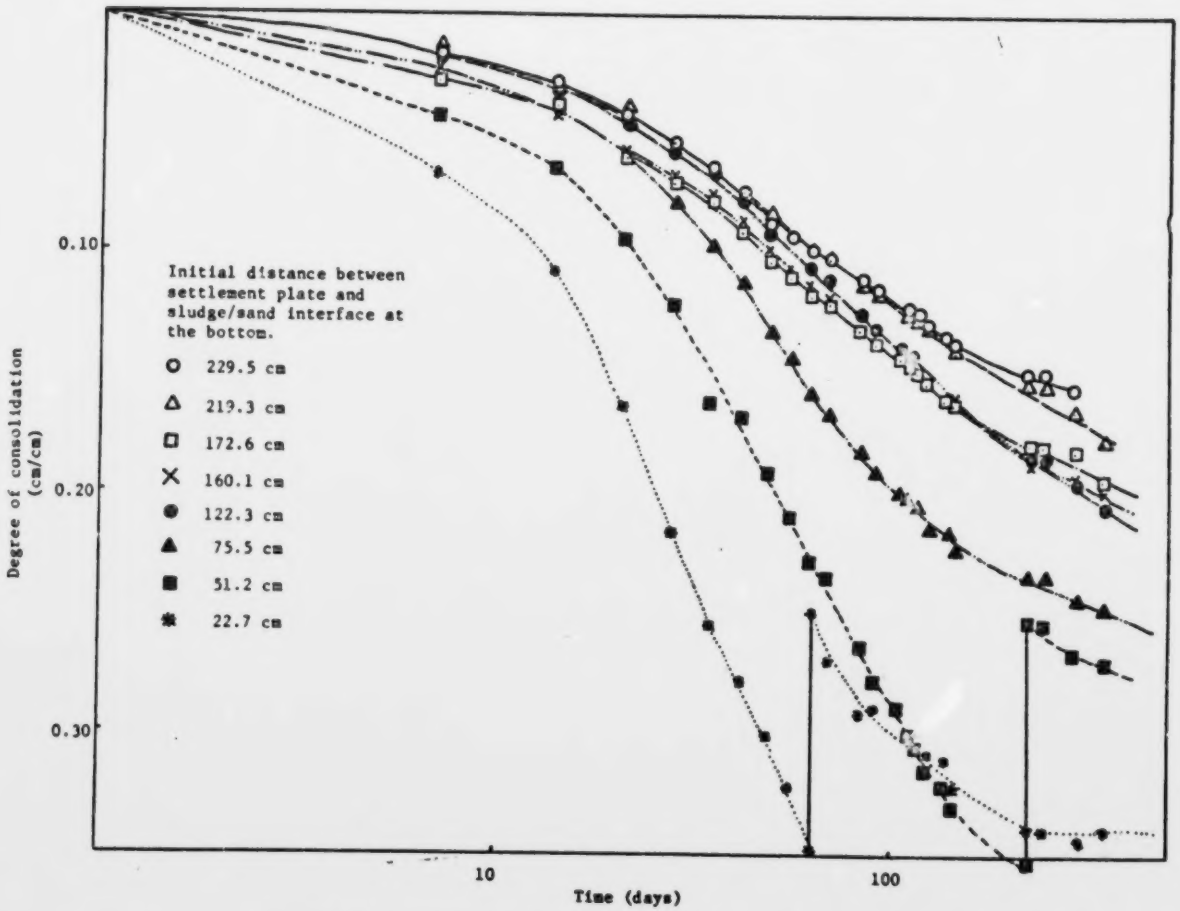



Figure 11. Consolidation of settlement plates located at different depths in a large unloaded sludgefill.

to dry the sludge to at least 50% moisture before the fill could support loads without flowing. The field experiments indicated that wet sludge layers less than two feet deep can be dried from 35 percent solids to 50 percent solids in three to six weeks by natural air drying. Placement of this dried sludge resulted in a fill with low consolidation and high bearing capacity and strength. These dried fills appear to internally yield after prolonged loading. Tests to evaluate the sheer strength of dewatered sludge indicated an increase in strength as solids content increased, but above 58 percent the strength decreases and the sludge was observed to crumble. The sludge in these tests was not compacted and higher sheer strength can be achieved with compaction.

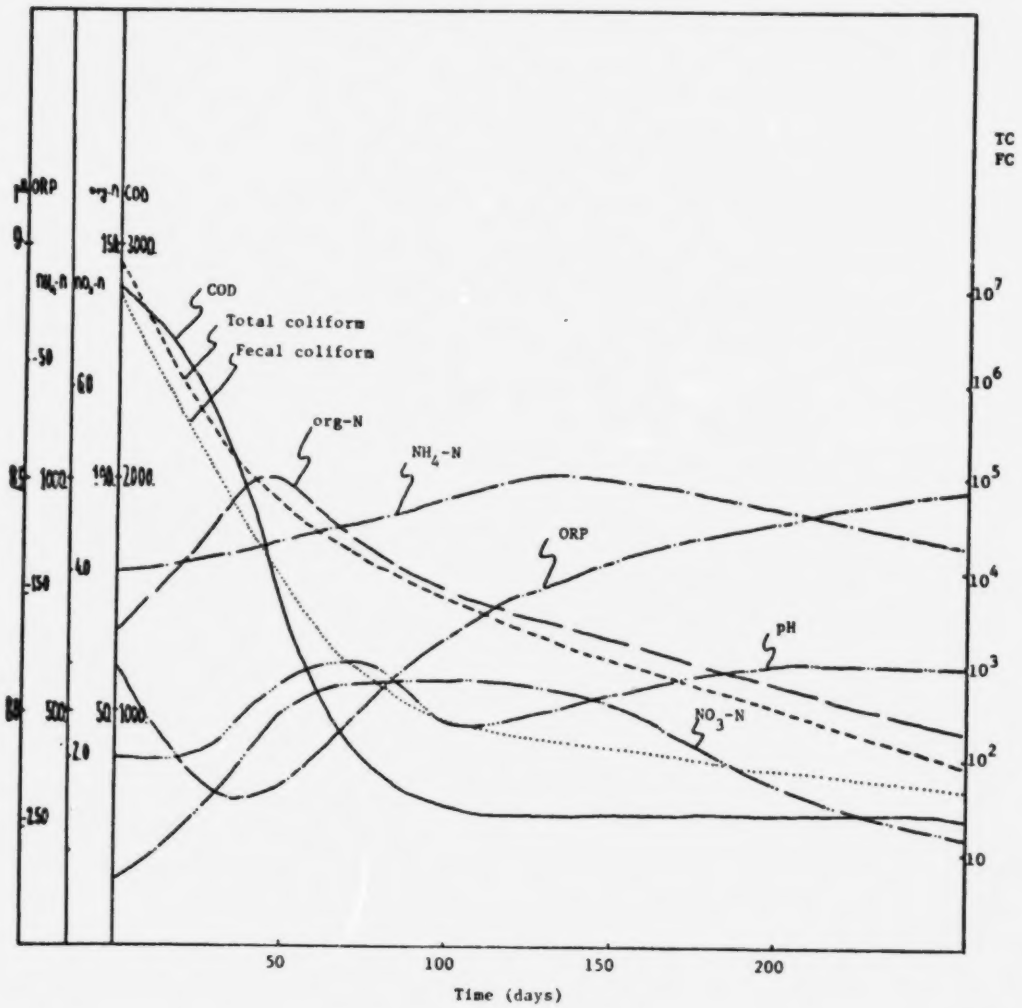
## LEACHATES

The amount of leachate from a deep fill was collected and analyzed. The dewatered sludge loses a significant fraction of its water through drainage; the dried sludge was observed to drain for less than two months. Chemicals appear sequentially in the leachate in a similar pattern to biological degradation products in water. COD is observed to diminish, followed by decreases in organic nitrogen, ammonia, and then nitrate. A maximum concentration of alkalinity and conductivity is observed between the ammonia and nitrate peaks. The COD peak at 45 cm. of sand below the fill was observed seven weeks after the fill was placed. Figure 12 shows the results of a series of pore water observations showing this typical release pattern of biological degradation products.

The environmental effects of the large scale sludge fill operation have been monitored by the monthly observation of total and fecal coliform samples offshore. No observable increase was noted, but the background levels were high from severe overflows in the adjacent waters. The effects of these factors have to be determined first in order to estimate the possible contribution of coliform leaching from under the dike. It was observed that during periods of very low tide the ground water level in the fill and under the seawall flowed outward. The $Cl^-$ content of these streams was generally lower than that of Puget Sound, indicating that a major portion of this water originated from the low $Cl^-$ containing groundwater. The use of heavy metals from sludge as tracers indicates that leachates are penetrating the seawall.

Dry landfilled sludge does not appear to absorb rainwater and a major portion of this water will be runoff. Due to the difficulty of measuring the runoff in the large scale operation, laboratory experiments were performed with slope surfaces placed under a 20° angle using different slope length and different

Figure 12. Changes of the chemical components in the interstitial water in the large sludge cells about 60 cm below the surface. The components are expressed in ppm, except pH (pH-units) and the total and fecal coliform (MPN/100ml).



rain intensities, to determine the amount and the chemical composition of the runoff water. Results indicate a very low runoff coefficient for wet sludge, but higher runoff in dry sludge. Concentration of pollutants in the runoff were higher from the wet sludge.

The fecal and total coliform concentration in the sludge cells (Figure 13) seems to be independent of the observed moisture content or sand or vegetative cover. It was found that when the COD/N ratio approached 40, growth conditions for the coliform organisms were always favorable and that aftergrowth would be observed. For example, it was observed that the COD/N ratio in one instance was 73 at the start of the operation and during four to six weeks decreased to around 40. The coliform population could transform its steady decrease into a growth after reaching this COD/N ratio. The opposite was also observed and a low COD/N ratio could increase till the point that aftergrowth would occur.

In one instance the pathogenic organism Salmonella was isolated from the sludge in relative high numbers. However, the FC:Salmonella ratio was much higher than normally encountered in bottom muds and polluted waters, indicating that anaerobic digestion and sludge land filling did decrease the Salmonella concentrations.

Sludge samples are also being analyzed for heavy metals, because it may turn out that the metals show a high specific absorption to the sludge particles and that the amounts detected in the leachates are much lower than those actually present in the sludge. Preliminary results indicate heavy metal concentration in sludge cake to be much lower than national averages.

Virus analysis of digested sludge indicates high concentration of virus particles strongly absorbed to the sludge cells. Experiments are still underway.

Landfilling of sludge may represent its ultimate disposal, but landfilling can also be a temporary solution and can then be used as long as necessary to improve the physical, chemical, and biological properties of the sludge (increase in strength, decrease of pathogenic organisms, etc.) A more beneficial use of the sludge may be that of soil conditioner or as land reclamation material. The use of sludge to grow field crops has been investigated by the University of Illinois (9) and the results of this study support their observations on leachates and health impacts.

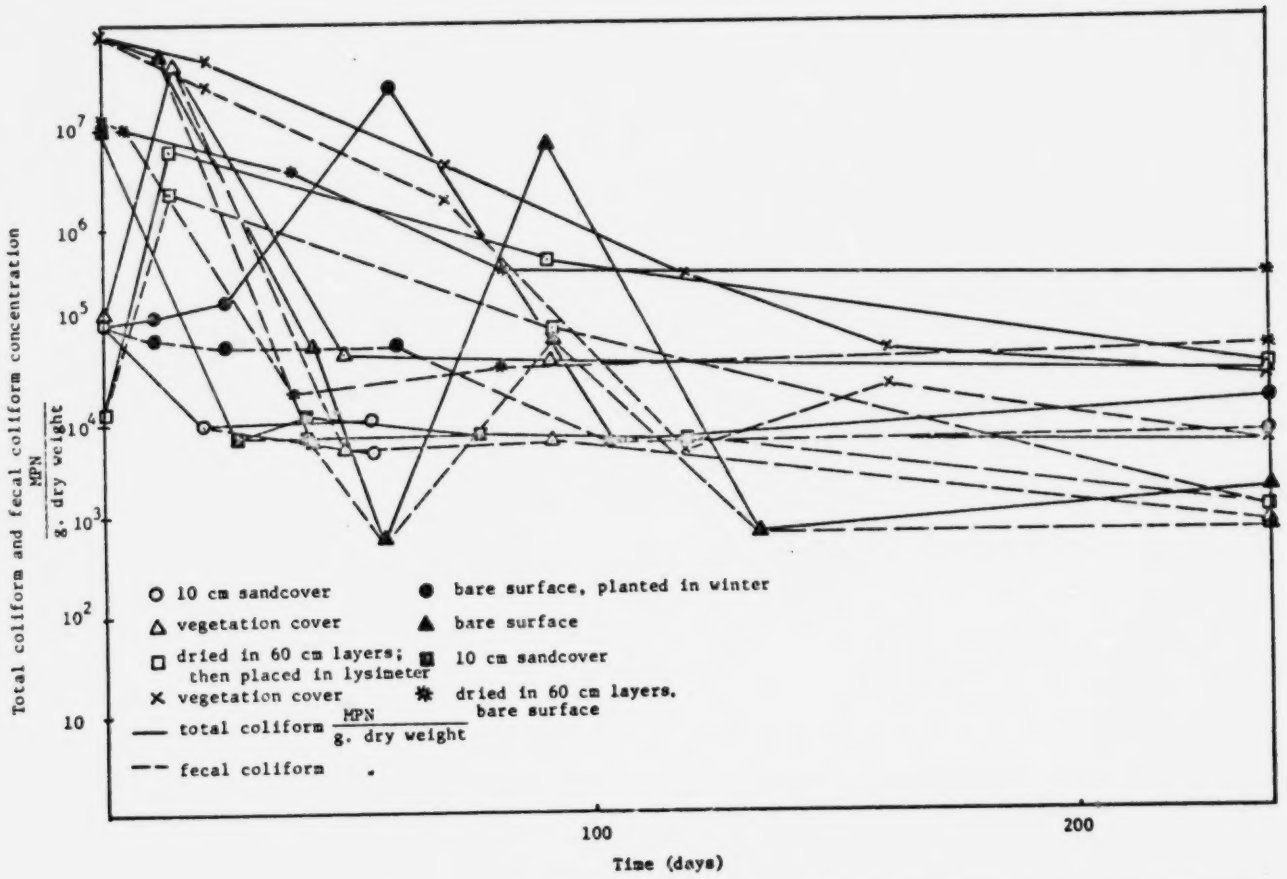



Figure13. Coliform die-off curves for the large scale sludgefills. After-growth occurred when the COD/N ratio reached a value of 35-40. Even after 200 days a large residual concentration remained in the sludge. The coliform concentrations were determined in samples collected from the upper 100 cm of the sludgefills, that had bare surfaces, sandcovers and vegetative covers.

Based on the above observations, it can be concluded that the optimal management of the sludge fill includes the further dewatering and drying of the centrifuged sludge to increase its strength. This can easily be done during spring and summer operation, after which the dried sludge (dried up to 50-60 percent TS) can be piled in 10-foot layers and covered with a 2-foot sand layer which seals the dried sludge effectively by its weight and will, therefore, prevent leaching. During rainy periods, the wet sludge should be stored in 10 ft. high piles to minimize its surface and the subsequent surface runoff. During drier periods the sludge can be spread in 1-2 ft. layers and dried subsequently. Another alternative, that was not investigated, is the use of drying beds in covered green houses for winter storage and dewatering of sludge cake.

DRYING

A major research effort (7) was established to evaluate the physical process of water flow in sludge under drying conditions and the role vegetation can play in this process. The initial step was to obtain experimental data for the radiation and energy balance of sludge exposed to ambient weather conditions. A well known characteristic of sludge is the rapid drying of the surface layer and the subsequent resistance to water flow from the lower layers. Both the literature and laboratory studies indicate that evaporation from sludge was restricted to the top six inches and that vegetation could increase by a factor of two the water loss from sludge layers thicker than six inches.

Sludge cake from the centrifuge was placed in several test containers and water loss observed. During a 130 day observation period beginning in late summer, vegetation removed approximately 30 pounds per square foot of sludge surface. This figure represents the net change and includes rainfall of 61 pounds per square foot area that fell on the sludge. Deep fills that were not covered with vegetation lost approximately half this amount, and fills that were covered with four inches of sand lost no weight. During the first 30 days of this test water loss from the bare and vegetation fills were similar, after this time the bare sludge surface crusted and increased resistance to evaporation while the vegetation took root and transpired the water from the fill. Based on these data, a total of at least 60 pounds per square foot of surface area could be removed each summer in the Seattle area. Experimental results from the drying experiments are shown in Figure 14.

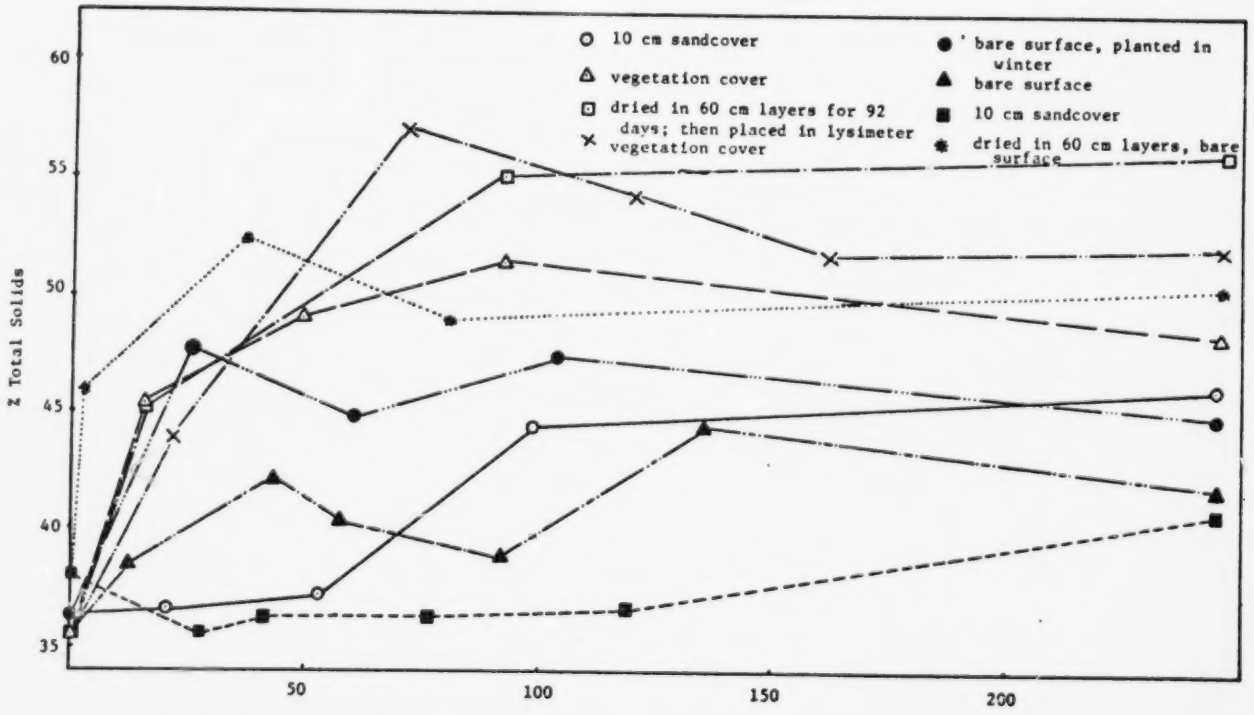



Figure 14. Drying curves for the large scale sludge fills with bare surface, vegetation cover and sandcover. All experiments started in the summer of 1969 and little rewetting occurred during the subsequent rainy winter period. The % Total Solids was determined from an integrated sludge sample of the upper 100 m. of the fill.

One of the significant results of the drying study was the development of methods to predict the drying rates of sludges. An extensive series of meteorological data were taken at West Point as part of this research. These data were used to evaluate several theories concerned with sludge drying. Based on these data it was shown that significant differences existed between the data reported at the official weather station and that at West Point. Since the cost to establish a permanent station at West Point was high, a method based only on net radiation measurements was developed to predict sludge drying rates. This method provided accuracies with only ten percent differences from measured results. Since the predictions with complete on-site weather data still have three percent errors, the cost of these additional data are not justified. It is recommended that drying times for sludges placed on any date can be specified as a function of the integrated net radiation received by the sludge (7).

TABLE 2. Field Drying Experiment

| Activities | Output |
| --- | --- |
| Energy and Water Balance of Sludge<br><br>Sludge was placed in 8 ft. diameter test cells resting on weighing systems. This allowed the determination of each parameter of the water balance equation. Also, the parameters of the energy balance were measured like net radiation, soil heat flux and evaporation. | Sludge placed in excess of 4 ft. layers showed that drainage was not an important factor in dewatering sludge. Due to overburden pressure the lowest layer became compacted resulting in a marked decrease in permeability. Soil heat flux usually was small and seldom exceeded 5% of the energy received at the surface by net radiation. Net radiation changed strongly with type and wetness of the surface. With the forming of a crust net radiation input was reduced by almost 40% as compared to dark, wet sludge. |
| Influence of vegetation as an active mean to lower wastes content<br><br>Rye grass was grown from seeds. The vegetation took root after approximately 30 days. Usually a waiting period of 7 to 10 days was required before the seeds could be put on the sludge. The growth in the first summer was good. The second vegetation period showed luxuriant growth. Vegetation was planted on two 8 foot diameter cells. | Vegetation, after growth started had a marked influence on drying rates. Net radiation input over vegetation was 60-80% higher than over bare sludge where a thin dry crust had formed. Therefore 60-80% more energy was available for evaporation of water. Especially during the second vegetation period higher transpiration rates could be observed due to the excellent growth. |
| Impact of sand layers on sludge drying<br><br>In small scale experiments under green house conditions 22 gal. cans filled with dewatered sludge were exposed to | A marked difference in drying rates between bare wet sludge and sand covered sludge was observed. Bare sludge showed 200% greater drying rates than the sand covered |

| Activities | Output |
| --- | --- |
| drying conditions. One set was covered with 8 inches of sand. | one. However, after the dry crust had formed over the bare sludge, drying rates were similar. |
| Correlation of micro climate at West Point with surrounding weather stations<br><br>Meteorological parameters such as temperature, wind speed, rainfall and humidity were recorded at the site and compared with standard weather data from Sea Tac and City of Seattle. | These data showed marked differences with West Point. Especially precipitation differed greatly from Sea Tac and City of Seattle indicating the need for a rain gauge installation. |
| Drying potential of West Point Climate<br><br>All important meteorological parameters were recorded continuously every 15 minutes. They served as input to test several theories predicting drying rates. | It was found that integrated daily measurements of net radiation were accurate within 10% on a ten day basis. Using on-site measurements of additional parameters such as temperature, windspeed humidity improved the prediction to a 3% error. |
| Filling methods and their impact on drying rates<br><br>Dewatered sludge was placed in different depths to investigate the dependence of drying from the thickness of the layers. Used were 8 foot diameter cells five, eight and ten feet deep and small pits 20 by 50 feet and two and four feet deep. | Atmospheric conditions influenced the drying only to a depth of 6 inches in the case of bare sludge independent of layer thickness. Water removal by drainage, usually was restricted to the lowest 12-20 inches because of the low permeability. The root system of vegetation went down approximately 24 inches in the second growing period. |

## SECTION VIII

## FULL SCALE DEMONSTRATION

The full scale placement of sludge began in the summer of 1971. Sludge was transported from the centrifuge facility to the diked area and dumped. The sludge dried in the diked area with the characteristic hard crust forming in a few weeks. In the winter months, with heavy rains occurring, the sludge crust did not form and the runoff was absorbed. In addition, digestion continued in the fill during the winter months.

Prior to the heavy rains, the sludge placed and dried in the summer was collected and placed in cells, similar to the practice employed in a sanitary land fill. The cells were approximately 20 feet wide, 8 feet deep, and approximately 50 feet long. Approximately two feet of sand was used as a cover for the cell. Once placed and covered, the cell could support the trucks transporting sludge to the lagoon. In some cases steel matting was used to distribute the load.

The sludge placed in the diked area during the winter gained moisture and was transferred by a "clam shell" to a large open cell the next spring to dry. The concept will be to use the dried winter sludge and the sludge dried during the spring and summer for fill next fall, using the cell construction that proved successful last fall.

No difficulties were encountered with transport and movement of the sludge when dried to 50% solid content. Loaders, trucks, graders, and conventional earth-moving equipment with large rubber tires were successfully employed in the fill operation.



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## SECTION IX

## ANALYSIS OF DEMONSTRATION

The results of this demonstration indicate that wet digested sludge can be placed in an intertidal zone in a manner that would create a stable fill. There appear to be several problems with the methods and processes employed in the demonstration project, as well as some unanswered environmental impacts that preclude the use of wet digested sludge to develop parks without further research and development. In addition, there may be sludge disposal alternatives that would be more feasible than the one demonstrated in this study.

### DEWATERING

The major problem and cost encountered in this demonstration was the dewatering of digested sludge to a moisture content that could be used for fill. As reported earlier, the centrifuge selected for this demonstration had high maintenance and low solids recovery characteristics for West Point sludge. These problems were compounded by a design decision to employ a pump rather than belt cake handling system. With a belt type system and acceptance of a high maintenance program, digested sewage sludge could be dewatered to 50% solids (wet basis, 100% moisture dry basis). This pattern of operation would require two centrifuges, since fifty percent maintenance down times were experienced.

One of the conclusions of this effort was the lack of engineering design data for centrifuge facilities, and the need to pool these data if future facilities are to be designed. Based on this experience it is recommended that:

1. Sludge cake pumps require high maintenance and limit the cake dryness that can be transferred--it is recommended that such pumps not be used and belt systems be employed.

2. Diesel engines should not be used as a prime mover for a centrifuge because of noise and limited range of speed control.

3. Further research must be provided before the flocculation and shear of particles produced by chemical addition in the centrifuge are understood sufficiently for sludge recovery application.

4. Centrifuges should be run continuously, since short term runs permit solids to build up in the device and create imbalance and severe vibrations.



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The high labor cost for dewatering was a result of design and can be significantly lowered by the use of an electric drive for the centrifuge, a belt cake transmission system, and a small cake storage pit to reduce labor requirements. Additional automatic controls would not increase the facility cost significantly, but would decrease the labor cost from $15 per ton to less than $10 per ton.

The inherent problem of low solids recovery and high maintenance cannot be overcome easily. These problems were much greater than anticipated and another dewatering process should be evaluated. Filtering is being considered as an alternative, but the lower solids content of the filter cake may not be suitable for fill.

FILLING

The placement of dewatered sludge in a deep fill presented minimal operational problems when the solids content was higher than 50 percent (weight solid/total weight). Solid content on a weight basis is not a good parameter for classifying sludge. Sludge from a combined sewer system may contain 50 percent inorganic grit with a density of 150 pounds per cubic foot, while sludge from a sanitary sewer may be low in grit and organic in nature. A fifty percent solids (weight basis) sludge will have a volume fraction of 50 percent water for sanitary sludge, but similar sludge (same weight percent of solids) from a combined sewer will have a volume fraction of 60 percent water. This additional volume of water provides significant fill differences.

Since the sludge pump and centrifuge maintenance problems dictated that 40 percent (weight basis) was the maximum solids that could be produced, there were problems encountered in wet weather when the sludge was placed in the fill. The sludge tends to flow at 40 percent solids and also had a greater tendency to rewet in the rain. Both these characteristics increased the fluidity and moisture content of fills created during the rainy season. The wetter the sludge became, the more it would flow, and the greater would be the surface area exposed to the rain. By placing the sludge in very deep fills that are restrained on the sides to prevent flow, the surface area exposed to rain can be minimized. The use of plastic tarp covers could eliminate the rewetting totally.

During the spring, summer, and early fall the sludge can be placed in layers not greater than two feet deep and air-dried to 50 or 60 percent solids content. Sludge of this composition can be handled with conventional earth-moving equipment and placed in fills up to 10 feet deep. When a top cover of

several feet of sand is used, this fill appears to be consolidated to a stable fill configuration with minimal leaching or rewetting. The air drying step can be eliminated if mechanical and thermal dewatering could be used to produce 50 to 60 percent solids. Vegetation can be used to accelerate drying in the warm months, but must be removed in the winter to avoid rewetting of the fill (diffusion through root structure).

The filling of an intertidal zone with sludge requires a seawall to maintain a dry fill area. It is the consensus of the consultants to METRO that the construction of a seawall that is impervious to sea water is difficult and expensive. Since the diked area used in this study had been filled and then excavated years later, it may be unique in its ability to prevent sea water intrusion. This impermeability was an advantage in retaining leachates as well as a possible disadvantage in this demonstration since fresh water runoff from the highlands adjacent to the diked area was trapped in the diked area. The only solution was to pump these waters back to the treatment plant. The cost of the seawall in sludge disposal will be determined by the ratio of the length of seawall required per ton of fill. A cost of $5 to $10 per ton of sludge for the seawall was estimated for this demonstration project. Interest rates and inflation can easily double these costs in future projects.

Finally, partial digestion creates digested sludge that is quite active. The gas production after the first month of placement creates swelling of the sludge (a factor of two). The impact is not serious if the sludge is air-dried before placement. A solution for gas production is included in the discussion of the health impact.

## ENVIRONMENTAL IMPACT

The dewatered sludge appears to be a reservoir of nutrients, heavy metals, BOD, coliform and other pollutants. Leachates from a deep fill contain these pollutants, but each pollutant appears to be released at a different time. Air-dried sludge with 50 percent solids or greater were observed to have minimal leachates. A possible solution would be to dry the sludge on a well drained bed and treat the leachate, or to use an impervious bed and restrict the water loss to evaporation. The dried sludge could be placed and consolidated to form the impervious layer.

Some citizens of the region have expressed a high value for intertidal lands, thus the original concept of land reclamation in intertidal zones may not be consistent with current social values. The results of this study can be applied to

landfills and the placement of dewatered sludge on any marginal lands. The vegetation studies indicate a high growth potential for plants on sludge and the use of sludge to landscape freeway right-of-ways and other public lands may be more appealing than land reclamation. Such disposal would eliminate the need for dewatering and permit spraying of the sludge that is drawn from the digesters. Approximately 100 acres could assimilate all the sludge from the West Point System. There are at least several hundered acres of freeway right-of-way within 30 miles of the plant that could be used for sludge disposal. This land has nominal public access and would avoid possible health problems encountered in deep sludge fills.

The other environmental impact that would arise from a centrifuge dewatering operation is the poor quality of centrate. When chemicals are not used to increase recovery, the maximum solids capture may not exceed fifty percent. Thus one half of the solids in the sludge will not be captured and could be discharged to the environment. Typical operation data are shown in Figures 15 and 16. Only one polyelectrolyte was found that could capture more than 90% of the sludge solids in the cake. The dosage required was more than 30 pounds per ton ($60 per ton). With or without chemicals, change in centrifuge speed to increase cake solids reduced solids recovery significantly. METRO is proceeding under other funding to demonstrate alternative dewatering processes that capture more solids. The research results of this study indicate that the centrate can be treated biologically or chemically, but this could double the dewatering costs.

## HEALTH IMPACTS

The most serious problem encountered in this demonstration was the residual coliform population that remained in the settled sludge. Aftergrowth of coliform was observed any time the COD/N ration approached 40. This was observed for both increasing and decreasing ratios of COD/N. More important, a large residual population of coliform was observed to remain in the sludge after many months. The demonstration period was less than a year, so the die-off of coliform over long periods has not been assessed. If deep fills are to be used, the monitoring of coliform levels for periods of years is required. Covering with sand may contain the pathogens in the lower sludge layer and protect public health.

While chlorination (before centrifuging) may reduce the coliform population, the published literature and our experiments indicate that this is not an effective preventive health measure for deep sludge fills. Chlorination can, however, reduce the biological activity of the dewatered sludge and

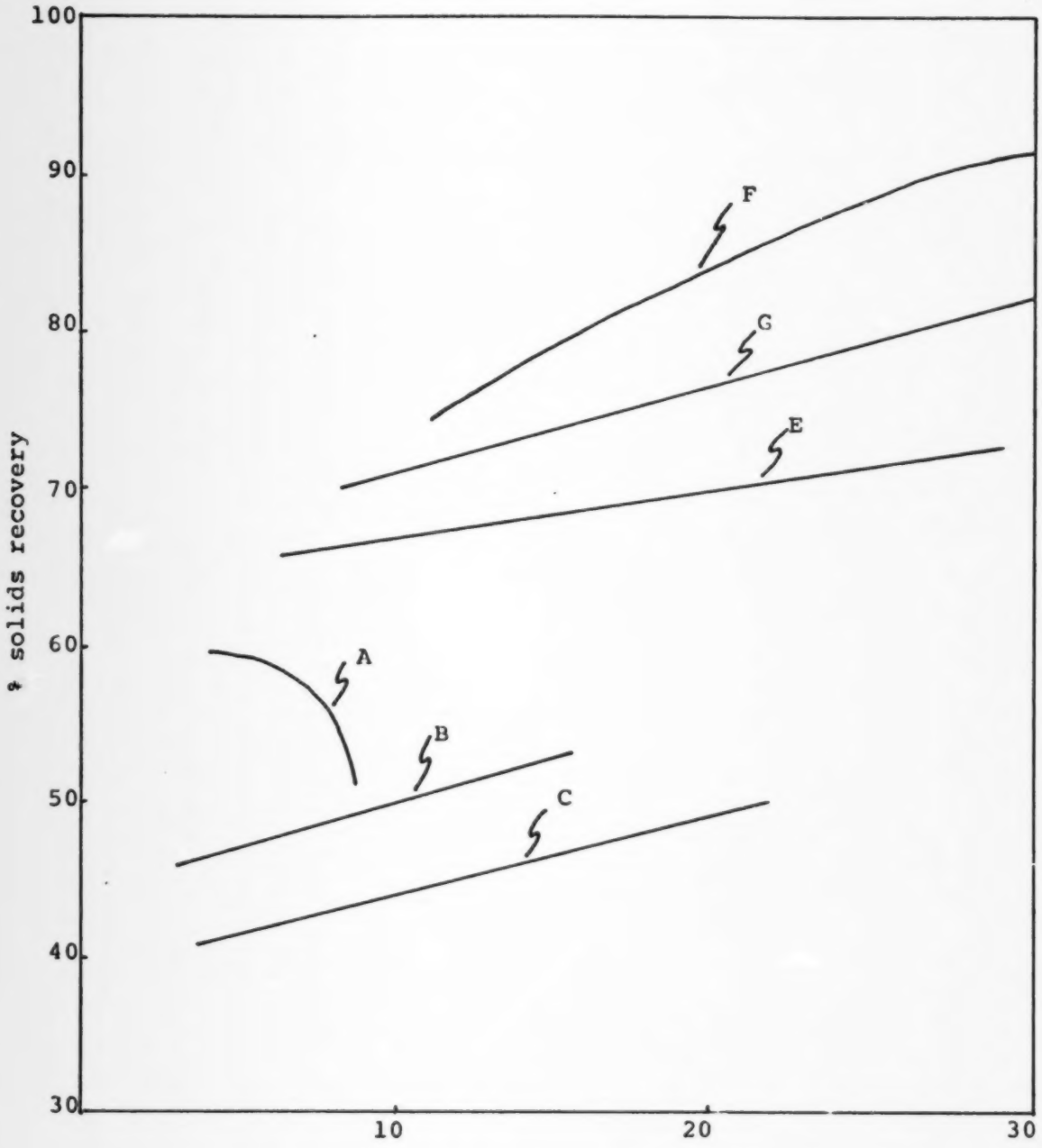


Figure 15. Centrifuge Operation Data with Chemicals.

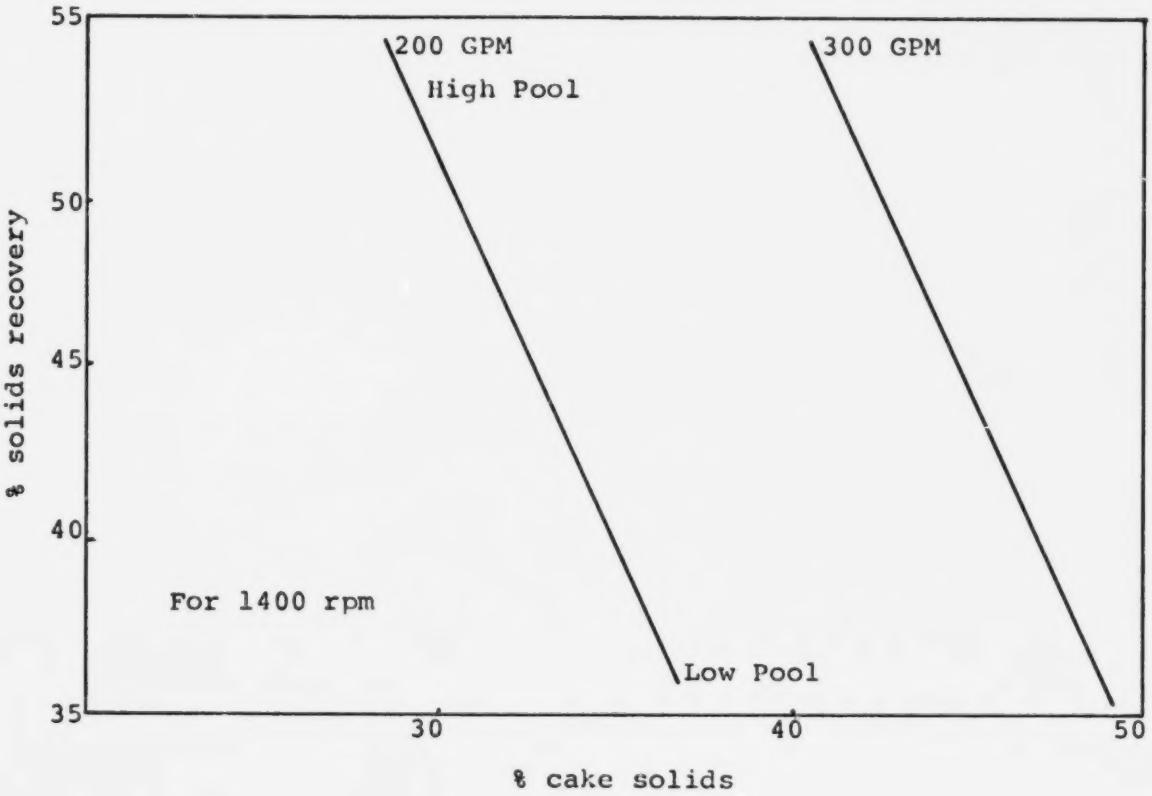


Figure 16. Operating Data for Centrifuge (at 1400 rpm and a pool depth of 2 - 3.75).

prevent gas formation and swelling of the fill. Data is lacking to justify coliform as a valid pathogenic organism indicator for treated sewage sludges. Each agency will have to weigh the survival of coliform versus the doubt that pathogens will survive in their evaluation of this disposal method. The evaluation of pathogen and virus survival is a costly investigation and could not be conclusively resolved in this study.

If deep sludge fills are to be employed either long term die-off must be established or a method to disinfect the sludge found. A possible solution may be the use of heat as a disinfectant and sludge conditioner; another could be the complete drying of the sludge, or the aerobic drying of sludge in thin layers. These alternatives have been shown to be effective, but no practical method has been demonstated. Other methods such as chemicals or ultrasonic treatment may be effective, but their effectiveness has not been demonstrated.

The outlook for competitive sludge disposal alternatives may have better protection for health, but has particular problems. For example, incineration, if proper burning is achieved and proper air cleaning provided, will still have an ash disposal problem of high solids. Other forms of land disposal such as spraying, soil conditioning, etc., have health impacts as well as high land requirements.

If deep fills are to be constructed, some action is required to reduce the biological activity of the sludge. As mentioned earlier, the gas production can cause major swelling of the fill. The practice of METRO to provide high rate digestion may need to be modified in order to provide a supernating stage to settle the solids and provide complete digestion. Unfortunately the West Point Plant is not designed to permit operation of a digester in a supernating mode. There are no mechanisms provided to remove the digester solids if they settle and high rate mixing must be maintained. Sludge from facilities that can supernate will be less active and have better digestion.

The only practical solution for the West Point facility is to evaluate chlorination, heat treatment, and monitor the fill for an extended period. Since the test results indicate that the leachate from these fills can be minimized, a deep fill that is fenced may be acceptable. Fencing is in direct conflict with a park use concept and may not be an acceptable solution. The other hopes may be rapid die-off as the moisture content of the compacted fill decreases, or containment of pathogens by sand cover. These results may take five years or longer to observe.

Results from the Illinois sludge project indicate sludge contains toxic agents that could be destroyed by addition of biochemical compounds and by autoclaving. Since this study indicated that growth depended on COD/N ratio, additional research is required to define control methods for pathogens in sludge. The toxic agents prevented seed germination as well as coliform growth, indicating that heat-treated sludge would support a vegetation cover earlier after placement.

## ECONOMICS

The total cost of sludge disposal by construction of deep fills is difficult to estimate. There are many costs, such as centrate treatment, sludge pretreatment, leachate control, and fill finishing that could not be defined accurately in this research. The basic cost of dewatering the sludge was $23 per ton. Operation and design improvements could reduce this cost in half, but the use of chemicals to increase solids recovery could easily double this cost. In regions which have higher levels of solar radiation and lower levels of precipitation, the dewatering costs will be lower, since drying in place would increase. Also the cost of a seawall would add $5 to $10 per ton, and centrate treatment $20 per ton. This would indicate that sludge disposal with deep fills would cost a minimum of $25 per ton and could increase to as high as $75 per ton, if all environmental impacts were negated.

If costs are above $20 per ton for sludge disposal, the potential of transporting to remote sites for soil building or for disposal becomes attractive. Some studies indicate that sludge can be transported several hundred miles for $20 per ton. If sludge can be sprayed on the land, the dewatering can be eliminated, thus avoiding the $23 per ton experienced in this demonstration but add substantial transportation costs. The consideration of off-site disposal was outside the scope of this research project but it is an option that requires consideration on the basis of economics. Both the transport of liquid and solid sludge should be investigated. Approximately 100 acres of land would be required for the West Point Plant output. This type of disposal would avoid the public health problems, since aerobic biological degradation has been proven to be effective. The environmental impact could be minimized by employing application rates that would permit all the liquid to evaporate instead of percolating into the ground water. There would be a problem in the Pacific Northwest to find a disposal area which is not either frozen (Eastern Washington) or saturated (Western Washington) in the winter. This may require a disposal system that has storage facilities for three or four months of sludge. For the West Point facility this would have to store about 5,000 cubic yards of de-

watered sludge. The storage concept has not been thoroughly evaluated, but can offer cost saving in the fill operation. The daily placement of 10-15 yards of sludge is much more costly than an operation that would place 5,000 cubic yards in a few days. This large scale operation can employ earth-moving equipment at much lower labor costs per ton of sludge.

In summary, the economics of deep sludge filling were very disappointing. Very high maintenance and labor costs were encountered in the dewatering operation, and even though dewatering cost may be halved by improved design, the cost of centrate treatment or increased sludge recovery appears to be very high with the system demonstrated. Methods to insure a fill with no health impact were not demonstrated and additional costs may occur. The cost to develop park land with sludge was found to be an order of magnitude greater than land fill with sand.

## FUTURE PLANT EXPERIMENTS

One of the difficulties in demonstrating a new process in a large treatment plant is the expense of flexibility in operation. Experimentation with an existing plant the size of West Point may not provide more information than a 10 mgd plant. Several times in this demonstration, exploration of the pretreatment of sludge, post-treatment of centrate, and different operation of the digesters was impossible because of the expense and the disruption of normal plant operations.

It is recommended that METRO design and construct or modify one of their small treatment facilities to be the experimental station for the system. Equipment should be designed for multiple direction flow in the system and even permit bypass of the sewage to the main system. Since there is excess capacity in the system, a plant of 10 mgd could be inserted in the system to test all aspects of treatment. This would permit realistic scale testing of treatment concepts without perturbing normal operations and protection of environmental quality. A special staff or experimental operations and administration personnel could use the plant as a training center.

## SECTION X

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## SECTION XI

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** These technical reports are also available as University of Washington Ph.D. theses and are available from University Microfilms, 300 North Feeb Road, Ann Arbor, Michigan 48106.

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